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LUNAR MISSION SAFETY AND RESCUE

PREPARED FOR
NATIONAL AERONAUTICS & SPACE ADMINISTRATION
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HAZARDS ANALYSIS AND SAFETY REQUIREMENTS

LOCKHEED MISSILES & SPACE COMPANY
A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION
SPACE SYSTEMS DIVISION • SUNNYVALE, CALIFORNIA

LUNAR MISSION SAFETY AND RESCUE

HAZARDS ANALYSIS
AND
SAFETY REQUIREMENTS

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LOCKHEED MISSILES & SPACE COMPANY
SPACE SYSTEMS DIVISION
P. O. Box 504, Sunnyvale, Calif. 94088



Lunar Surface EVA - Apollo 14 Mission

FOREWORD

This report was prepared by the Lockheed Missiles & Space Company, Sunnyvale, California, and contains the results of a Lunar Hazards Analysis and Safety Requirements Study performed for the National Aeronautics and Space Administration, Manned Spacecraft Center, under Contract NAS9-10969, Lunar Mission Safety and Rescue Study. This is one of the following four reports documenting the contract findings:

Lunar Mission Safety and Rescue - Executive Summary
MSC-03975, LMSC-A984262A

Lunar Mission Safety and Rescue - Technical Summary
MSC-03976, LMSC-A984262B

Lunar Mission Safety and Rescue - Hazards Analysis and
Safety Requirements
MSC-03977, LMSC-A984262C

Lunar Mission Safety and Rescue Escape/Rescue Analysis and Plan
MSC-02978, LMSC-A984262D

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Glossary

SYMBOLS, ABBREVIATIONS, AND DEFINITIONS

AMU	Astronaut Maneuvering Unit (generic term)
Activation Time	The time required to ready the rescue vehicle and crew for a rescue operation following receipt of the alert signal
Backpack	Portable Life Support System (PLSS) carried on the back of an astronaut (generic term)
Base	Lunar Surface Base (generic term)
Buddy System	Two or more men working together in the same location and environment
CC	Crew Compartment used to house and transport men on the PTV and tug (generic term)
Communications Lag	The time required for the distressed crew to communicate a request to the rescue crew
C-PTV	Chemically Powered Prime Transport Vehicle (generic term)
Delta V or Delta Velocity	Change in vehicle velocity in inertial space
Earth Vicinity	A general, unspecified location in Earth orbit or on Surface
EC/LSS	Environmental Control/Life Support System (generic term)
ECS	Environmental Control System (generic term)
EMV	Extravehicular Maneuvering Unit (generic term)
Escape	Utilization of on-hand equipment and resources, without outside assistance, to effect immediate removal from the proximity of danger
ESS	Emplaced Scientific Station (generic term)
FD	Propellant Depot (generic term)
Flyer	Generic term for any flying vehicle designed for limited travel over the lunar surface (LFV)
G&N	Guidance and Navigation
Hazard	Presence of a potential risk situation caused by an unsafe condition, environment, or act

IPP	Integrated Program Plan
IVA	IntraVehicular Activity
LCG	Liquid Cooled Garment
Lander	See Lunar Lander Tug (LLT)
LEAP	Lunar Escape Ambulance Pack
LESS	Lunar Emergency Escape System
LFV	Lunar Flying Vehicle (Flyer)
L ₂ Libration Point	Point of stable equilibrium in orbit on the far side of the Moon
LLT	Lunar Lander Tug (generic term); space tug with landing gear
LM	Lunar Module
LMP	Lunar Module Pilot
LOD	Lunar Orbit Departure
LOI	Lunar Orbit Insertion
LRV	Lunar Roving Vehicle (Rover)
LSB	Lunar Surface Base
LSSM	Lunar Scientific Survey Module
Maneuvering Work Platform	Platform designed for use in working on the exterior of an Orbiting Lunar Station
Mev	Million Electron Volts
MOLAB	Mobile Laboratory
MPL	Manned Payload
N-PTV	Nuclear-Powered Prime Transport Vehicle (generic term)
OLS	Orbiting Lunar Station (generic term)
OPS	Oxygen Purge System (generic term)
PDD	Project Description Document (produced by NASA-MSD)
PDI	Powered Descent Initiation
PGA	Pressure Garment Assembly

PLSS	Portable Life Support System or Backpack (generic term)
PTV	Prime Transport Vehicle used to transport personnel and cargo between Earth orbit and lunar orbit (generic term)
RCS	Reaction Control System
Rescue	Utilization of outside assistance to effect a return to a safe haven
rem	Roentgens equivalent man
Response Time	The span of time between the occurrence of an emergency and the placement of the stranded crew into a temporary or permanent safe haven
RNS	Reusable Nuclear Shuttle (N-PTV) (generic term)
Rover	Generic term for any lunar surface transport vehicle moving on tracks, wheels, etc. (LRV)
Safety	Freedom from chance of injury/loss
SLSS	Secondary Life Support System (generic term)
Survival	Refers to the utilization of resources immediately at hand to extend the lives of crewmen to permit escape or rescue
Survival Time	Refers to the maximum length of time that a crew can live following an emergency, using resources immediately at hand
Space Tug	Multipurpose vehicle used to transport men and cargo in lunar orbit and to the lunar surface (generic term)
Tug	Space Tug
TEI	Transearth Injection
Tumbling	Random angular motion about any axis
ΔV	Delta velocity

SECTION 1

INTRODUCTION

This report presents the results of work performed by the Lockheed Missiles & Space Company for NASA-MSC, under the hazards analysis subtask of Contract NAS9-10969, during the period June 15, 1970 to March 15, 1971.

1.1 Objectives

The objectives of the hazards analysis portion of the Lunar Mission Safety and Rescue Study were to:

1. Identify potential hazards in lunar orbital and surface operations, crew activities, functions, and environments.
2. Determine the effects of the identified hazards on crew safety.
3. Develop corrective measures for the identified hazards, including hazard detection and preventive and remedial concepts.
4. Identify hazardous situations wherein rescue might be required.
5. Establish essential guidelines and requirements for risk reduction in advanced manned lunar exploration.
6. Identify requirements for additional analyses and technology development pertinent to crew safety.

1.2 Scope, Ground Rules, and Assumptions

The study was limited to the lunar sphere of influence and to the 1980-1990 time period.

Lunar orbital activities were defined to commence at lunar orbit insertion and conclude either during spacecraft contact with the lunar surface or upon completion of the transearth maneuver.

Lunar surface activities were defined to commence with the final flight phase immediately preceding spacecraft touchdown on the lunar surface and to conclude once the crew had returned to a lunar ascent vehicle and ascent had begun.

The design and routine internal operations of major lunar orbital elements such as the Tug, Nuclear Shuttle, and Orbiting Lunar Station were assumed to be optimized and were not studied. Failure of the elements to accomplish their intended mission, and operational hazards between independent elements, were postulated or identified and analyzed.

No probability analyses were performed during the study. Hazards were identified and analyzed even though the probability of occurrence might be low.

Current planning and definition of the Lunar Integrated Program Plan (IPP) was accepted as a baseline for the study and as a point of reference, but the analysis and results were kept general enough that the guidelines will be valid even though the IPP elements and operations change. Where terms such as Tug, Orbiting Lunar Station, and Lunar Surface Base are used, no specific concept, shape, size, capacity, or mass are implied, and only functions are indicated.

The results of Apollo flights, in particular flights No. 11, 12, and 14, were used freely in the analysis. In addition, the results of current contracted studies relative to the Space Tug, Orbiting Lunar Station, Reusable Nuclear Shuttle, and complementary safety efforts were made available by NASA and were used.

The study was concerned only with hazards to personnel and not with loss of equipment or property.

1.3 Approach

The approach to the Hazards Analysis subtask is illustrated in Fig. 1. Hazards characterization includes the definition of a hazard, the hazard levels, and the hazard groups. These are presented in Appendix A. The definition of a hazard and the hazard levels were taken from MSCM-1702, "System Safety Program

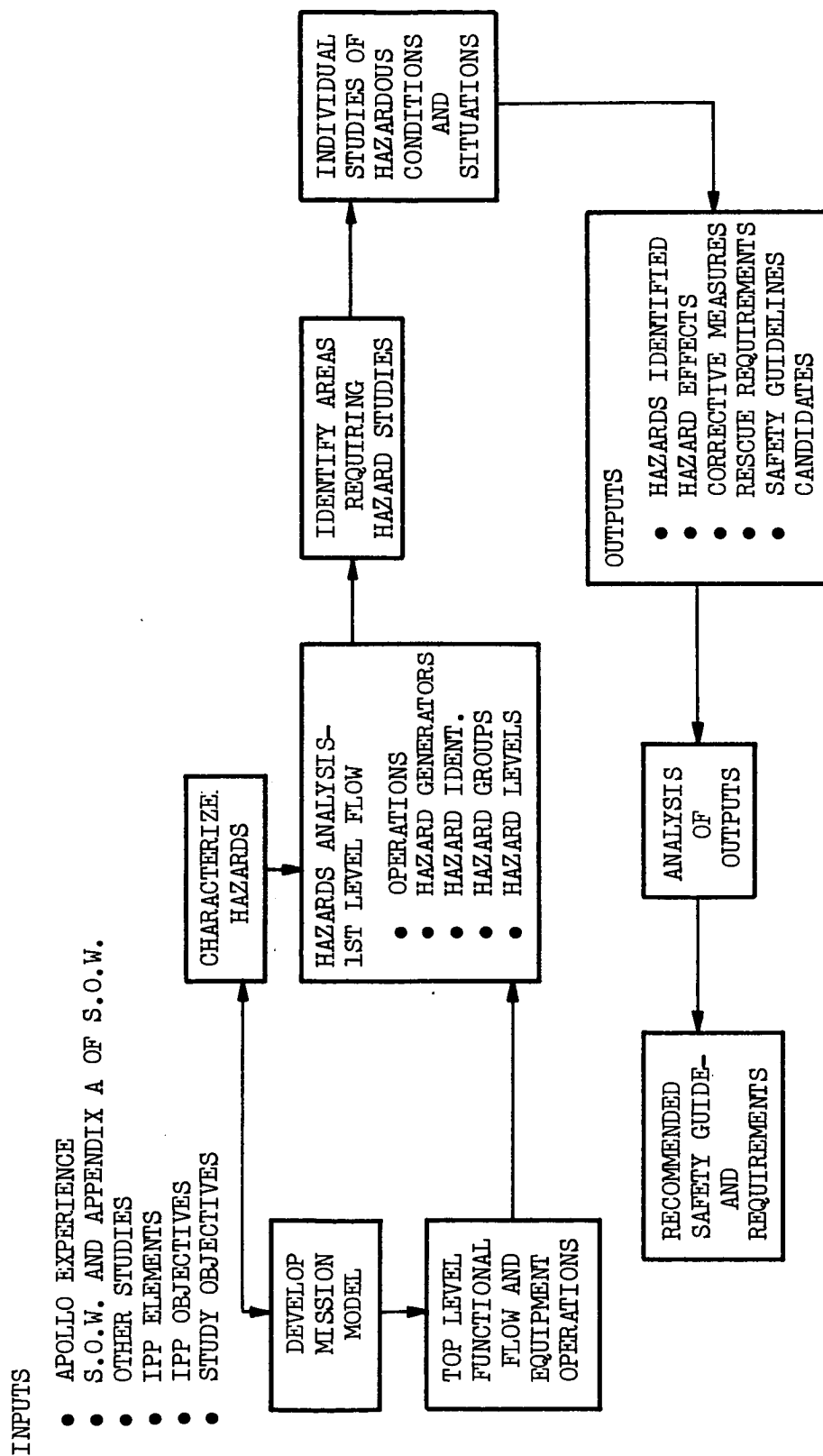


Fig. 1 - Hazards Analysis Approach

Requirements for Space Flight Contractors". NASA-MSC Houston, Texas (not dated), while the hazard groups were derived as a part of the study effort.

The mission model was based on the Lunar Integrated Program Plan (IPP) and Project Description Documents (PDD's) and represented a lunar exploration program for engineering development and scientific exploration in the 1980's. The model was used as a point of departure throughout the study in the search for ways to enhance safety. Additional detail is presented in Appendix B.

Typical lunar exploration equipment elements and their usage are illustrated in Fig. 2 and listed as follows:

- . Transportation between Earth Orbit and Lunar Orbit
 - Nuclear Shuttle
 - Chemical Shuttle (alternate)
 - Lunar Lander Tug (emergency return)
- . Operations in Lunar Orbit
 - Orbiting Lunar Station
 - Lunar Lander Tug (normal and rescue)
 - Propellant Depot
 - Consumables Capsules
 - Unmanned Satellites (scientific, communications, etc.)
- . Transportation between Lunar Orbit and Lunar Surface
 - Lunar Lander Tug (normal and rescue)
- . Operations on the Lunar Surface
 - Lunar Lander Tug (normal and rescue)
 - Lunar Surface Base
 - Roving Vehicles (normal and rescue)
 - Flying Vehicles (normal and rescue)
 - Science Equipment (emplaced stations, drills, telescopes, etc.)
 - Support Equipment (elec. power, trailers, supply cannisters, etc.)

Lunar mission operations examined in the study included the following.

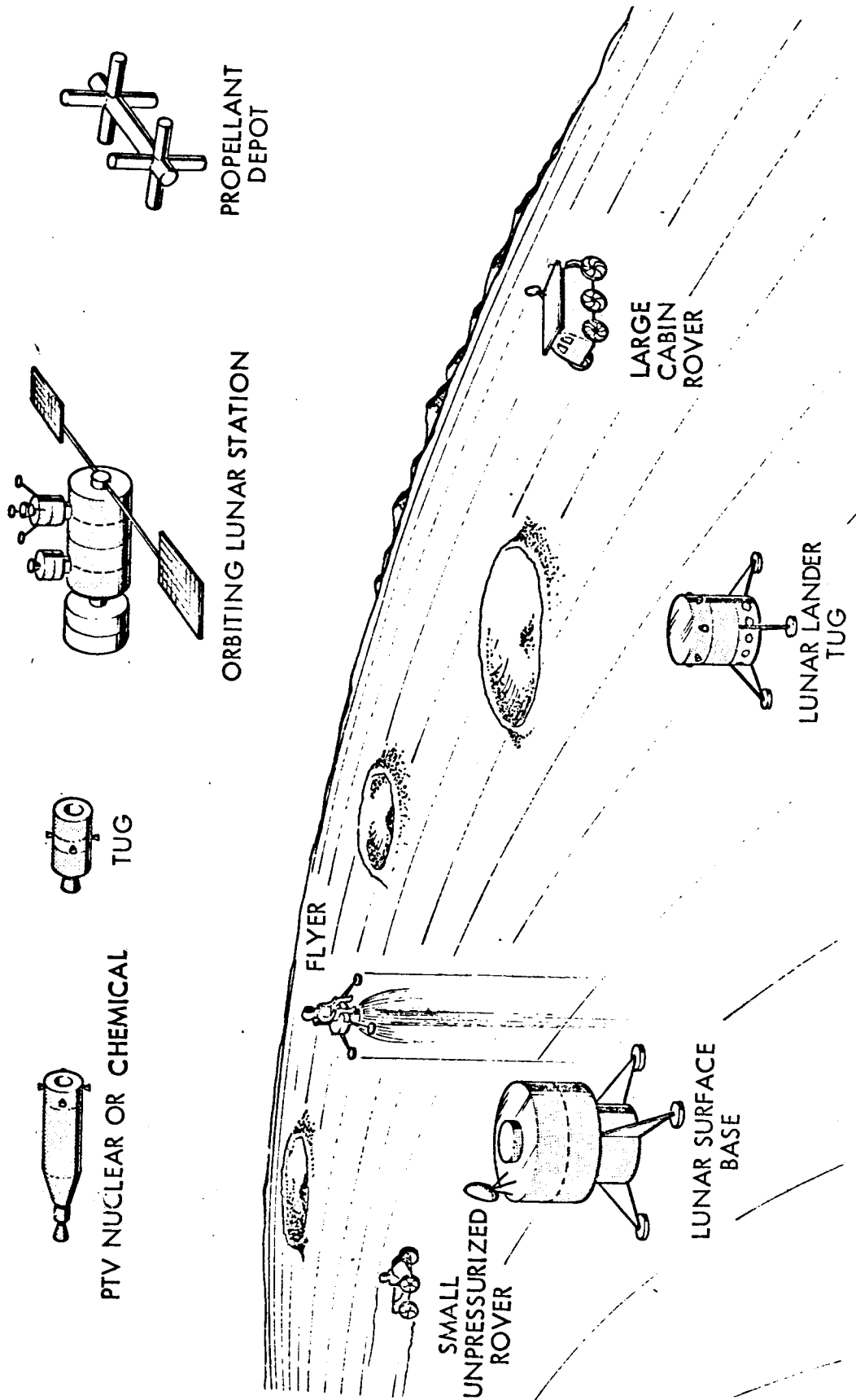


Figure 2 Typical Lunar Exploration Equipment Elements

<u>Earth-Moon Shuttle Operations</u>	<u>Orbital Operations</u>	<u>Surface Operations</u>
Transport Payload	Rendezvous & Docking	Deployment
Lunar Orbit Insertion	Operations Base	Exploration
Trans-Earth Injection	Orbit Keeping & Transfer	Technology & Engineering
Rendezvous & Docking	Resupply	Science
Stationkeeping	Maintenance	Resupply
Contingency Operations	Tug Refueling	Maintenance
	Technology & Engineering	Walking
	Science	Driving (Roving)
	Extra Vehicular Activity	Flying
	Satellite Place & Service	Escape/Rescue
	Escape/Rescue	Contingency Operations
	Contingency Operations	

The methodology developed to carry out the hazards analysis is presented in Appendix C. Working from study objectives and the mission model, the top-level functions and operations of lunar exploration elements were described. This was expanded in a first-level flow chart to identify potentially hazardous conditions and situations requiring study. The top-level and first-level hazards assessments are presented in Appendix D.

Working from the first-level hazards assessment charts, and from knowledge of the planned future missions, a list of conditions and situations requiring further hazards analysis was compiled, and individual Hazard Study efforts carried out. From each Hazard Study the potential hazards were identified, effects described, corrective measures proposed, rescue requirements noted, and candidates for safety guidelines proposed. When the individual studies were complete, a study of safety guidelines candidates was made to assess compatibility and feasibility, and to firm up the recommendations which appear in MSC 03976.

Certain data generated to support the individual Hazard Studies, or to suggest approaches to improving safety, are presented in Appendix E as Supplemental Data Reports.

Symbols and abbreviations used in this report are defined in the Glossary.

Section 2

HAZARDS ANALYSIS RESULTS

The hazards analysis methodology is described in detail in Appendix C. This methodology was used to prepare the top level functional flow diagram, to perform the first level hazards assessment presented in Appendix D, and to develop a list of conditions and situations requiring individual hazard studies. This section presents the individual Hazard Study results in total. Each Hazard Study is, in general, complete in itself and may be separated from the document for use by a reader interested only in a specific subject. The complete listing of Hazard Studies is presented in the Table of Contents.

Following completion of the Hazard Studies presented here, an analysis was performed to extract the significant hazards and the recommended guidelines and requirements to prevent or remedy those hazards. These hazards and guidelines are summarized in Section 2 of MSC 03976.

The situations leading to a requirement for rescue are identified in each Study. These were made available to the Escape/Rescue subtask effort wherein rescue requirements were developed in detail and escape/rescue guidelines and a rescue plan were prepared and documented in MSC 03978.

HAZARD STUDY 1
PRIME TRANSPORT VEHICLE (PTV) IN AN UNCONTROLLED
TRAJECTORY - FAILURE OF PTV TO ACHIEVE LOI

INTRODUCTION

This study considers the hazards to man resulting from a failure of a prime transport vehicle (PTV) to achieve Lunar Orbit Insertion (LOI). The PTV may be either chemical or nuclear powered.

ASSUMPTIONS

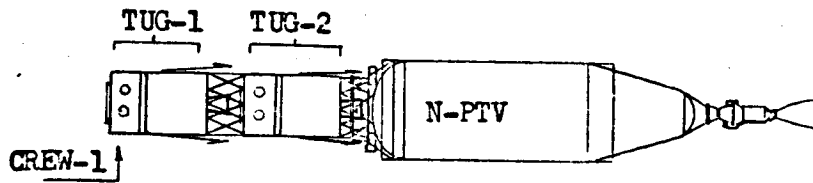
The following conditions are assumed for purposes of the analysis:

- Case 1. The PTV is transporting the first crew and Tug payload for the initial manning and activation of an orbiting lunar station (OLS). The crew is located in the crew module of a man-configured, fully loaded Tug vehicle. The Tug is provisioned for a nominal 28-day mission.
- Case 2. The PTV is transporting a replacement crew and resupply consumables to a currently manned and active OLS. The replacement crew is located in a crew compartment docked to several cargo containers which are in turn docked to the PTV. The crew compartment has no independent propulsion capability.

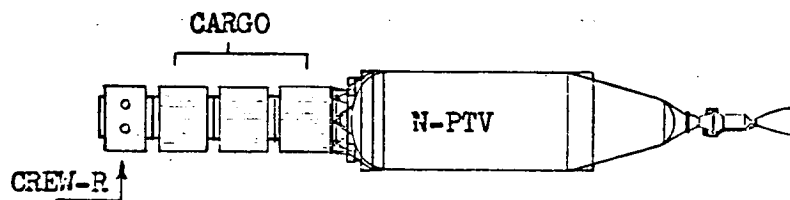
The OLS is in a 60 nm circular orbit.

Navigation update is provided from Earth base.

The PTV configurations for the two conditions considered are as follows:



INITIAL MANNING CONFIGURATION



SUBSEQUENT MANNED MISSION CONFIGURATION

Additional data for this study are presented in Appendix E, Supplemental Data Report No. 1.

THE MAJOR HAZARDS

The primary function failures which defeat the achievement of an LOI are as follows:

- a. Degradation or loss of vehicle navigation capability.
- b. Degradation or loss of vehicle orientation capability.
- c. Degradation or loss of primary propulsion capability.

Of these three primary function failures, the degradation or loss of vehicle navigation capability is the least likely to prevent LOI, since navigation errors of that magnitude could scarcely elude the attention of Earth stations and the on-board crew. It is presumed that the crew would be provided with

the capability (and up-date information from Earth base) to manually direct the vehicle to the target position. Thus, this particular function failure would not be permitted to develop into a hazard generator.

Regardless of which function failure triggers the inability to achieve lunar orbit insertion, the resultant hazardous situation generated for Cases 1 and 2 is:

Crew personnel are aboard a disabled PTV in an uncontrolled lunar escape trajectory.

The potential major hazards to man evolving from this situation are as follows:

- (a) For Case 1 - First Crew Delivery:
 - 1. Temporary stranding of crew aboard a disabled PTV.
 - 2. Potential loss of crew if the disabled PTV failed with excessive rates/motions.
- (b) For Case 2 - Subsequent Crew Deliveries:
 - 1. Potential loss of stranded crew on board disabled PTV.
 - 2. Probable loss of stranded crew if disabled PTV has failed with excessive rates/motions.
- (c) For both cases the PTV may be on an Earth return trajectory.

ANALYSIS OF IDENTIFIED HAZARDS

The effects of the major hazards resulting from the inability of the PTV to accomplish an LOI maneuver are considered for two significant function failure modes:

- (a) For an assumed function failure causing loss of main propulsion capability but with attitude control capability intact.
- (b) For an assumed function failure causing loss of vehicle orientation capability.

Hazard Effects:

The loss of main propulsion capability disables the PTV and places the on-board crew in the hazardous situation of being temporarily stranded in a coasting vehicle on a lunar escape trajectory.

The loss of vehicle orientation capability presents the same hazardous situation except that the vehicle may have acquired a rate vector or motion in some axis other than the desired flight vector. The severity of the residual rate or motion could have serious effects upon the crew well-being and survival capability and on escape/rescue.

The fate of the PTV in either event ranges from potential heliocentric orbit insertion, or geocentric orbit insertion if the lunar approach velocity is sufficiently low. It is also possible for the PTV trajectory to result in Earth impact, though analysis of this hazard is beyond the scope of this study.

Corrective Measures

PTV Delivery of First Manned Payload

Preventive measures:

The capability of the PTV to accommodate critical function failures via redundant systems employing a fail-operational approach is primarily a basic system and subsystem design problem. The capability of the PTV to continue critical operations in a contingency mode is judged to be of prime importance in its manned configuration.

Remedial Measures:

For the first crew delivery mission, and any subsequent manned PTV mission

where a crew capsule configured Tug is a part of the payload, the crew has the option of employing the Tug as an escape vehicle for leaving the PTV. This presumes that the Tug is in a powered-up state at the time that an LOI is approached and further that the Tug can be rapidly disengaged from the PTV payload structure.

The remedial measures requirements in this case are:

- a. Provision for power-up the Tug at any time in a PTV mission.
- b. Provision for Tug guidance update on a continuously available basis.
- c. Provision for emergency separation of Tug from PTV docking or payload structure.
- d. Provision of direct PTV/EDS alert and warning output for Tug flight control station.
- e. Provision of contingency LOI procedures for Tug emergency utilization.

PTV Delivery of Subsequent Manned Payloads (Personnel and Cargo) - Case 2

For all missions following the delivery of the first crew (excluding subsequent Tug delivery missions), the transport mode employed for rotational crew delivery and return is the crew module. Basically, this unit is conceived to be a crew shelter cannister having a complete and self-contained life support system with facilities and provisions to maintain a crew during transit to and from the OLS. The module is dockable to other cargo modules and the OLS, and is moved about via a Tug to effect crew transfer operations. The most singular characteristic about the crew module is its complete lack of propulsion capability. The transport of personnel in this fashion transfers the responsibility for the safety of the passengers completely and irrevocably to the PTV and its operations.

Preventive Measures:

(A) PTV Considerations:

For the basic PTV, it will be necessary for the PTV to accommodate critical function failures through redundant systems and subsystems employing fail-operational criteria for stepping through available redundancies. Such procedures coupled with contingency operational modes for operating with degraded systems must be considered to be of prime importance.

(B) Crew Module Considerations:

In recognition of the fact that human efforts are fallible, it is prudent to insure that not only the systems on which man is dependent are close to failure free, but, that escape from disastrous consequences is possible in the event of a chance failure or accident. Therefore, in order to provide an adequate margin of safety for the survival and recovery of the crew-module it is deemed necessary to provide some minimal propulsion capability which would permit the crew and module to escape from a disabled or disabled and tumbling PTV and at least achieve an "await rescue" position in the vicinity of the PTV or even achieve an elliptical lunar orbit. The minimum propulsion capability required for the crew module to accomplish an elliptical lunar orbit insertion would be on the order of a 1000 fps ΔV . Data relative to the crew module escape from a tumbling nuclear PTV are presented in Appendix E, Supplemental Data Report No. 4. The module should have stabilization capability sufficient to permit the module to present a stable target for docking to a rescue vehicle. On board systems would include emergency communications equipment, a power system, a rescue beacon, and ECS/LSS. The fate of a crew in a crew module must not be solely dependent upon the carrier vehicle under any circumstances.

Remedial Measures:

Since the OLS is manned for all subsequent PTV crew delivery missions, Tugs stationed at the OLS are available for rescue operations. However, the use of

the Tugs for rescue or retrieval operations must be considered in the light of program resource-depletion, and hence, consideration must be given to the time element allowable in each rescue or retrieval event. Realistically, situations involving crew health and well being will require first order priority at the expense of resource depletion. It is because of this unpredictable requirement that logistic operations should be planned in such a way that the impact of a non-catastrophic mishap does not result in a major expenditure of resources. Thus, if a crew-module should leave a disabled PTV (which could not make the LOI) and enter in an await-rescue orbit, the resources cost of the "rescue" would be far less than if the Tug had to chase the PTV, retrieve the module, and return to the OLS (rescue Tug ΔV of 4,400 ft/sec vs 14,000 ft/sec). The above notwithstanding, crew-module rescue, or even PTV capture and retrieval, appears to be quite feasible in view of the Tug capabilities. The following three alternate remedial measures with respect to crew-module rescue are considered feasible:

1. A rescue vehicle (Tug with a ΔV capability of about 14,000 ft/sec standing by at the OLS is required to intercept the stranded crew and crew-module on a disabled PTV and return them to the OLS.
2. A crew-module with an on-board ΔV capability of 1000 ft/sec can leave the PTV and enter a lunar orbit. It then becomes possible for a rescue vehicle standing by at the OLS to recover the orbiting crew-module for a ΔV expenditure of only about 4400 fps. The weight for propulsion system plus propellant to provide a ΔV of 1000 ft/sec to a 10,000 lb crew compartment and 3,300 lb instrumentation unit is between 1500 and 2000 lb, depending on propellants assumed.
3. A crew-module with an on-board ΔV capability of 3000 ft/sec can leave the PTV, enter lunar orbit, and proceed to the OLS without need for rescue. Assuming that propulsion is added to provide a ΔV of 3,000 ft/sec to a 10,000 lb crew module and 3,300 lb instrumentation unit, the propulsion weight penalty would be between 4,500 and 6,000 lb, depending on propellants assumed.

Escape/ Rescue Requirements

For manned PTV missions with a Tug in the payload, escape capability for the crew utilizing the on-board Tug vehicle is a mandatory requirement. Emergency separation capability for the Tug under tumbling conditions is also required.

For manned PTV missions with a crew module, but no Tug, escape from a tumbling or partially destroyed PTV, plus rescue from lunar escape trajectory are required.

SOURCE DATA

1. Nuclear Shuttle System Definition Study - Phase III, Monthly Progress Report, LMSC-A980259, Nov 15, 1970.
2. Nuclear Stage, PDD, MSC. April 13, 1970.
3. Equivalent Chemical Stage, PDD, Vol III, May 5, 1970.
4. Chemical Propulsion Stage, PDD, MSC, July 1970
5. IPP Reference Schedule - High Budget, MSC, May 5, 1970.

HAZARD STUDY 1
SUMMARY OF SAFETY GUIDELINES

1. The crew of a prime transport vehicle shall be provided with navigation update information, and with the capability to manually direct the vehicle to the target position.
2. If the crew module of a prime transport vehicle (PTV) is mounted on a propulsion vehicle, such as a Tug, that Tug shall be in a powered-up state at the time of lunar orbit insertion or departure and shall be capable of rapid separation from the PTV to function as a crew escape vehicle.
3. Nuclear prime transport vehicles shall not be placed on a free Earth return trajectory leading to reentry at Earth.
4. During each manned prime transport vehicle arrival or departure at the the Moon, other operations in orbit and on the lunar surface shall be restricted to activities with low risk of generating a rescue requirement.
5. Crew modules, serving essentially as replacement-crew delivery shelters, shall be capable (as a minimum) of quickly separating and moving away from a disabled (stable or tumbling) prime transport vehicle. The crew module shall be capable of providing coarse attitude control, communications (beacon and voice) and life support while awaiting rescue.
6. During each manned prime transport vehicle (PTV) arrival and departure at the Moon a rescue vehicle, manned and ready, shall be on standby in lunar orbit to intercept a PTV that fails to achieve lunar orbit insertion or departure. This rescue vehicle, assumed starting from a 60 nm circular, coplanar orbit and returning to that orbit, shall have a minimum ΔV capability of 14,000 ft/sec.

The following two guidelines assume that the crew module is given a modest ΔV capability sufficient to place the crew into an elliptical lunar orbit, and are alternates to guideline No. 6, above.

7. The crew module shall have the capability to quickly separate from a disabled prime transport vehicle, provide a ΔV of 1,000 ft/sec to achieve an elliptical lunar orbit, and maintain attitude, communications, and life support while awaiting rescue.
8. During each manned prime transport vehicle arrival and departure at the Moon a rescue vehicle, manned and ready, and with a ΔV capability of at least 4,400 ft/sec, shall be standing by in lunar orbit (assumed to be 60 nm circular).

The following guideline assumes that the crew module is given a ΔV sufficient to allow the crew module to separate from the disabled prime transport vehicle and proceed to a safe haven in a 60 nm lunar orbit without assistance from a rescue vehicle. This guideline is an alternate to 6, 7, and 8 above.

9. The crew module shall have the capability to quickly separate from a disabled prime transport vehicle and provide all necessary life support and communications functions while continuing on to a safe haven in lunar orbit, assumed to be at 60 nm circular. The minimum ΔV capability shall be 3,000 ft/sec.

HAZARD STUDY 2

PRIME TRANSPORT VEHICLE (PTV) IN AN UNCONTROLLED TRAJECTORY - FAILURE OF PTV TO ACHIEVE TEI

INTRODUCTION

This study considers the hazards to man resulting from a failure of a prime transport vehicle (PTV) to achieve Trans-Earth Insertion (TEI). The PTV may be either chemical or nuclear powered.

DISCUSSION

Analysis has shown that the hazards, corrective measures, and candidate safety guidelines for this failure are essentially identical to those presented in Hazard Study 1 and Hazard Study 3. The PTV may still be in an orbit about the Moon, or may have achieved escape velocity at the time of the failure. Hazard Study 1 and 3 should be consulted for details.

HAZARD STUDY 3

UNCOOPERATIVE OR DISABLED PRIME TRANSPORT VEHICLE IN LUNAR ORBIT

INTRODUCTION

This study area addresses the situation of a prime transport vehicle (PTV), manned or unmanned, which becomes uncooperative or disabled in lunar orbit. The source of propulsive power may be either chemical or nuclear.

ASSUMPTIONS

1. The PTV failure leaves that vehicle in some orbit, about the Moon, varying from 60 x 60 nm to 60 x 11,800 nm.
2. For initial manning of an orbiting lunar station the PTV crew will be located in the crew module of a man-configured tug vehicle.
3. For crew exchanges the men are located in a crew compartment which has no independent propulsion capability.

Configurations for assumptions 2 and 3 are illustrated in Hazard Study 1 which should be considered in concert with Hazard Study 3.

THE MAJOR HAZARDS

The major hazards identified are:

1. Potential collision between a disabled PTV and another orbital vehicle.
2. Stranding of a crew aboard a disabled PTV.
3. Potential loss of crew aboard a disabled PTV that has failed with excessive angular rates.
4. Radiation hazard to other orbital vehicles if the PTV is nuclear powered.

ANALYSIS OF IDENTIFIED HAZARDS

Effects of Hazard 1 , Potential Collision

An uncooperative PTV in lunar orbit presents a potential collision hazard with other vehicles in orbit such as an orbiting lunar station, tug, or other PTV.

The consequences of a collision of an OLS with a disabled PTV in the operational orbit, where both vehicles have very closely the same orbital velocity, are not likely to be catastrophic in nature. However, damage to structures or appendages could result and the integrity of the PTV and OLS system could be violated. The potential effects to man may range over the following:

- a. Necessity for a potentially hazardous inspection and damage survey mission to ascertain future OLS and PTV usability and/or salvage potential. The mission would entail the capture (if possible) of the PTV and its removal to a safe parking orbit.
- b. Should the PTV be a nuclear vehicle which has suffered severe structural damage, a mission requirement will then exist for the remote capture of the wreckage for disposal purposes in order to remove the ultimate possibility of nuclear engine lunar impact.

For the case of a disabled PTV in elliptical lunar orbit having a 60 nm periapsis, collision with an OLS at the point of orbit coincidence would be of a catastrophic nature. The potential effects impacting later manned missions may range over the following:

- a. Injury or death to crewman involved.
- b. Necessity for a potentially hazardous inspection and survey mission to examine and possible deorbit large wreckage segments.
- c. If the PTV were a nuclear vehicle, the fate of the nuclear engine would have to be determined. If the engine were intact and orbiting, it would have to be remotely captured for deep space disposal. If the engine had impacted the lunar surface, the area of impact would

have to be identified for surface quarantine purposes. And finally, if the nuclear engine had disassembled as a result of the collision, it is probable that some portion of the debris would impact and the rest would remain in an indeterminate spectrum of orbits for varying lengths of time. This, of course, would lead to a somewhat random distribution of eventually impacting nuclear debris over a large portion of the lunar surface.

Corrective Measures for Hazard 1

Preventive measures:

1. Prime transport vehicles should preferably not be brought into the same or an intersecting orbit with other operational elements such as an orbiting lunar station, but should always operate from a higher orbital altitude.

Remedial measures:

1. Each vehicle in lunar orbit should be constantly aware of other traffic, be made aware of any emergencies or malfunctions that could present a hazard, and have the ability to maneuver to avoid collision.
2. Orbital tug vehicles should have the capability to capture and control a PTV in orbit in order to prevent collision.
3. If a collision is permitted to occur, rescue and medical aid will be urgently required.

Collision is discussed further in Hazard Study 11.

Escape/Rescue Requirements for Hazard 1

Rescue may be required to remove the crew of a disabled PTV from the threat of collision.

Effects of Hazard 2, Stranding of PTV Crew in Orbit

The crew of a prime transport that has failed in lunar orbit will be stranded and in need of outside assistance unless the crew module is self sufficient. On initial manning of an orbiting lunar station it is anticipated that the crew module will be attached to a tug which can be separated and used to proceed to the OLS unassisted.

Corrective Measures for Hazard 2

Preventive measures:

1. Stranding of a PTV crew in lunar orbit may be prevented by providing each PTV crew capsule with the capability to separate and proceed to the OLS. This would require attitude control and navigation capability plus a propulsive ΔV capability of about 2000 ft/sec.

Remedial measures:

1. A PTV crew stranded in lunar orbit must be provided outside assistance to remove them from the disabled vehicle and transport them to a safe haven such as an orbiting lunar station.

Escape/Rescue Requirements for Hazard 2

Rescue will be required if a PTV crew is stranded in lunar orbit.

Effects of Hazard 3, Tumbling PTV

A tumbling PTV will present a considerable hazard both to the on-board crew and to any subsequent rescue attempt. If tumbling rates are low, the crew may not suffer greatly but cannot easily be rescued. If tumbling rates are high, rescue may be rendered impossible and death occur if capability for escape and survival is not provided.

Corrective Measures for Hazard 3

Preventive measures:

No measures to prevent a prime transport vehicle from tumbling are identified beyond careful attention to reliability and redundancy in the associated sub-systems, and fail-safe provisions to prevent excessive angular rates.

Remedial measures:

1. The crew of a prime transport vehicle should be able to assume manual control of vehicle attitude in order to avoid or stop tumbling.
2. Means must be provided for the crew compartment on a tumbling PTV to separate, stabilize, and support the crew while proceeding to a safe haven, such as an orbiting lunar station, or awaiting rescue.

Escape/Rescue Requirements for Hazard 3

Means must be provided for the crew of a tumbling PTV in lunar orbit to escape and survive until rescue is accomplished. Rescue of the escaped crew will be required.

Effects of Hazard 4, Nuclear Radiation from Failed PTV

A nuclear PTV, failed in lunar orbit, presents a potential radiation hazard to the crew attempting to escape, to rescue crewmen, and to crews of other vehicles in orbit. The crew of a tumbling nuclear vehicle will almost certainly be required to escape without outside assistance, and must be able to depart the PTV quickly enough to avoid radiation damage. Appendix E, Supplemental Data Report No. 4, discusses velocity requirements when leaving a tumbling nuclear PTV and shows that propulsive capability on-board the departing manned payload will be required.

Corrective Measures for Hazard 4

Preventive measures:

1. Nuclear vehicles should not be brought into the same or intersecting orbits with other operational elements such as an orbiting lunar station, but should always operate at a higher altitude.
2. Rescue crews should not approach a tumbling nuclear powered vehicle unless adequate radiation shielding can be provided.

Remedial measures:

1. Crew modules, serving essentially as replacement-crew delivery shelters, should be provided the capability (as a minimum) to quickly separate and move away from a disabled (stable or tumbling) prime transport vehicle. The crew module should further be capable of providing coarse attitude control, communications, (beacon and voice) and life support while awaiting rescue or proceeding to a safe haven. The minimum ΔV required is about 100 ft/sec with a minimum propulsive acceleration of 0.1 Earth g.
2. An uncooperative nuclear PTV in lunar orbit must be captured and repaired or disposed of by placing it in a safe lunar orbit, return to Earth orbit, or injection to heliocentric orbit. Means for capture of a tumbling nuclear vehicle by another unmanned vehicle must be devised. The space tug should be developed to have this capability.

Escape/Rescue Requirements for Hazard 4

The crew of a disabled nuclear powered prime transport vehicle in lunar orbit must be able to escape that vehicle and survive, and a subsequent rescue will be required. The disabled PTV may be either stable or tumbling.

DATA SOURCE REFERENCES

1. Nuclear Stage Program Definition Document, MSC, 9 Oct 1970
2. Equivalent Chemical Stage, Vol III (of) Nuclear Stage Program Definition Document, MSC, 5 May 1970
3. Chemical Propulsion Stage Program Definition Document, MSC, July 1970
4. IPP Reference Schedule - High Budget, MSC, 5 May 1970

HAZARD STUDY 3
SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. Prime transport vehicles, whether chemical or nuclear powered, shall not be brought into the same or intersecting orbit with other operational elements such as an orbiting lunar station, and shall always operate from a higher orbital altitude.
2. Each manned vehicle in lunar orbit shall be constantly monitoring other traffic, emergencies, or malfunctions that could present a hazard and shall have the ability to maneuver to avoid collision.
3. Orbital tug vehicles shall have the capability to capture and control or dispose of any prime transport vehicle in lunar orbit. The PTV may be chemical or nuclear, stable or tumbling.
4. Crew modules, serving essentially as replacement-crew delivery shelters, shall be provided the capability (as a minimum) to quickly separate and move away from a disabled (stable or tumbling, nuclear or chemical) prime transport vehicle. The crew module shall further be capable of providing coarse attitude control, communications, (beacon and voice) and life support while awaiting rescue or proceeding to a safe haven. The minimum propulsive requirement is about 100 ft/sec with acceleration of 0.1 Earth g. A ΔV of about 2000 ft/sec would permit the crew to proceed to an orbiting lunar station without rescue assistance.
5. Rescue crewmen shall not approach a tumbling nuclear vehicle unless adequate radiation shielding can be provided.
6. Any uncooperative prime transport vehicle in lunar orbit must be captured and either repaired or disposed of by placing it in a safe lunar orbit, returning it to Earth orbit, or injection to heliocentric orbit.
7. The crew of a prime transport vehicle shall be able to assume manual control of vehicle attitude in order to avoid or stop tumbling.

HAZARD STUDY 4
ORBITING LUNAR STATION NOT FUNCTIONALLY OPERABLE/HABITABLE

INTRODUCTION

This study analyzes hazards associated with an orbiting lunar station (OLS) that becomes functionally inoperable or uninhabitable either before or at the time of initial manning, or while manned.

ASSUMPTIONS

1. An orbiting lunar station (OLS) has previously been stationed in lunar orbit unmanned.
2. One or more fully operable lunar lander tugs are docked at the OLS when men are entering or occupying the OLS.
3. The internal design, functions, and safety of the OLS are the concern of other studies and not examined here.
4. Crew compartments are provided with contaminant detection and removal equipment.
5. All critical life support system components are highly reliable and have redundant parts.

THE MAJOR HAZARDS

The major hazards identified are:

1. Insufficient time to don space suits or escape to adjacent, safe crew compartment following sudden loss of cabin atmosphere. It is assumed this could happen only following a meteoroid strike, collision, or explosion that ruptured the cabin pressure shell, or a fire.
2. Inadequate backup or emergency power and life support supply to allow time for subsystem repair, transfer to a nearby safe haven, or to await arrival of rescue assistance.

3. Illness or incapacitation or deprivation of oxygen following contamination of cabin atmosphere.
4. Injury and/or deprivation of life support following explosion or fire with an internal system such as a high-pressure gas storage vessel, pyrotechnic, or experimental device.
5. High angular rate following loss of the primary and backup station attitude stabilization systems.

ANALYSIS OF IDENTIFIED HAZARDS

To prevent an abnormal condition from becoming a threat at the time of initial manning the following measures should be taken.

Preventive measures:

1. Remote activation and checkout of the OLS prior to initial manning so that deficiencies or problems will be known and can be planned for in advance.
2. Provision of pressure suits and PLSS units, repair parts and tools, portable battery powered lights, and specific procedures for inspecting and repairing an inoperative OLS on initial manning.

Remedial measures for initial manning are not applicable.

The following descriptions apply to effects and corrective measures for failures occurring subsequent to initial manning of the OLS.

Effects of Hazard 1, Insufficient Time to Don Suits or Escape

Insufficient time to don pressure suits or escape to an adjacent, safe compartment following sudden loss of cabin pressure will result in loss of the crew.

Corrective Measures for Hazard 1

Preventive measures:

1. Escape to a separate pressurized compartment could normally be accomplished much more quickly than donning of a pressure suit. Action must be accomplished before cabin pressure drops to 1.7 psia (Ref. 1). Thus it is advisable to have multiple pressurized compartments available, with interconnecting passageway or airlock hatches open at all times but quickly sealable. The tug crew compartment, propulsion module, and instrument unit, assumed always present and docked to the OLS, is the preferred haven since this provides a complete support and communication system capable of separating from the OLS if necessary for safety. The compartment selected must have the capability to provide a safe haven for all crew members present until one of the following can be accomplished:
 - a. The station failure can be corrected
 - b. External assistance can be provided
 - c. The crew compartment(s) can be removed to a permanent safe haven

No remedial measures are identified for Hazard 1.

Escape/Rescue Requirements for Hazard 1

Rescue may be required if the station cannot be repaired by the threatened crewmen, or the tug has insufficient capability to transport the crew to a permanent safe haven.

Effects of Hazard 2, Inadequate Power and Life Support

Inadequate backup or emergency power and life support supply to allow time for subsystem repair, transfer to a nearby safe haven, or to await arrival of rescue assistance will result in loss of the crew following failure of a vital station subsystem.

Corrective Measures for Hazard 2

Preventive measures:

1. Each mission sequence must be planned such that a backup or emergency source of power, life support, and communication capability will be available at all times so that following loss of a primary source the crew can proceed to a safe haven unassisted or await rescue, whichever time is greater.

No remedial measures are identified for Hazard 2.

Escape/Rescue Requirements for Hazard 2

Rescue of a crew in lunar orbit with inadequate power and life support supplies may be required.

Effects of Hazard 3, Illness or Incapacitation Following Contamination

Contamination of cabin atmosphere will result in illness, incapacitation, or deprivation of oxygen if corrective action is not taken.

Corrective Measures for Hazard 3

Preventive measures:

1. Provision of oxygen mask, emergency pressure garments and/or pressure suits, or separate pressure compartment and ECS, and immediate use of one of these, following detection of contaminants.
2. Monitoring of cabin atmosphere to detect contamination and initiate corrective action before illness, incapacitation, or oxygen deprivation can occur.

Remedial measures:

1. Outside assistance, or temporary abandonment of the station may be required if contamination cannot be removed.
2. Crewmen suffering from breathing contaminated atmosphere must be provided clean air, a safe haven, and medical aid.

Escape/Rescue Requirements for Hazard 3

Rescue will be required if corrective measures are not taken to prevent illness or incapacitation from contamination.

Effects of Hazard 4, Injury or Deprivation of Life Support Following Fire or Explosion

An explosion or fire may have hazardous effects similar to Hazards 1 and 3, already discussed, and additionally cause injury to one or more crewmen.

Corrective Measures for Hazard 4

Preventive measures for Hazard 4 include those discussed for Hazards 1 and 3, plus the following:

1. High-pressure gas storage bottles, pyrotechnics, and hazardous experimental devices should be separated from the main cabin and from vital subsystems components by structures designed to help control an explosion or fire.
2. Pressures in high-pressure storage vessels should be monitored to provide explosion warning, and procedures developed to correct potential hazards.
3. Where multiple pressure compartments are provided in a system, crew members should not all occupy one compartment at one time.

4. Provision should be made in station design for sealing each pressurized compartment separately, and then remotely exhausting the atmosphere to extinguish a fire. (See note Page 2-26)
5. Fire extinguishers should be provided in each pressurized compartment.

Remedial Measures:

1. Crewmen injured by explosion or fire will require immediate medical assistance, provision of pure atmosphere, and removal to a safe haven.

Escape/Rescue Requirements for Hazard 4

A crewman injured by fire or explosion must escape to be rescued and provided a safe haven and medical aid. Removal to Earth may be necessary for adequate treatment.

Effects of Hazard 5, High Angular Rate

A rotating station in orbit could pose a hazard to crewmen ranging from negligible to catastrophic, depending on rotational rate, direction of acceleration, and duration. Prolonged rotation at rates on the order of 300 degrees/second will lead to unconsciousness and eventually death.

Corrective Measures for Hazard 5

Preventive Measures:

1. Attitude control thrusters should be designed to fail "off" to prevent excessive angular rates. Do not design systems with hot coils that are grounded in order to fire.
2. Backup attitude stabilization systems should be provided to arrest tumbling, should it occur, to allow repair or capture by an assisting vehicle. Means should be provided to detect and isolate a failed engine.
3. Space tugs docked to an orbiting lunar station should be capable of providing emergency attitude stabilization for the entire system, assuming the OLS attitude control system is inactive.

Remedial measures:

1. If preventive measures are not taken, provision must be made for crewmen to escape from a rotating orbital station.
2. It is recommended that study of methods for arresting tumbling of space vehicles by outside means be accomplished.

Escape/Rescue Requirements for Hazard 5

If preventive measures are not taken, escape and rescue will be required.

Data Source References:

1. "Analysis of the Required Operational Characteristics of Space Escape Systems," Vol. III, J. E. Moeller, et al. N.A.R. Nov 1967, SAMS0-TR-67-7
2. "Fire Extinguishment in Hyperbaric and Hypobaric Environments."
J. Howard Kimzey, NASA Manned Spacecraft Center, presented to the NASA Conference on Materials for Fire Safety, Houston, Texas, May 6-7, 1970

NOTE:

Following the completion of the technical study effort, the advisability and effectiveness of evacuating a cabin atmosphere to extinguish fire was questioned. Tests discussed in Reference (2) have shown that in an open-celled polyurethane-foam fuel in pure oxygen (5 to 16.2 psia), the cells trapped oxygen and the ignited fuel continued to burn until the pressure was dropped to 0.12 psia in two minutes.

It is recommended that further testing be carried out in mixed gas and in pure oxygen atmospheres with materials now considered acceptable for use in space cabins.

Reference (2) also describes the test of a high-expansion, breathable, foam extinguishing agent composed of approximately 300 parts gaseous oxygen (the ambient gas in the test chamber) to one part of water-based solution. This agent was found to be quite effective and to show promise for future applications.

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HAZARD STUDY ⁴

SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. Provision shall be made to remotely activate and checkout an orbiting lunar station which has been taken to lunar orbit by an unmanned transport vehicle.
2. A crew sent to activate a defective unmanned orbiting lunar station shall be provided with pressure suits and PLSS units, repair parts and tools, portable battery powered lights, and specific procedures for inspection and repair.
3. Development of safe and effective means for arresting the rotation of a tumbling station in orbit by outside means shall be a prime requirement.
4. Each orbiting lunar station shall have more than one pressurized compartment capable of supporting the crew. Hatches to interconnecting passageways or airlocks shall be kept open at all times, but quickly sealable in an emergency.
5. Each orbiting lunar station shall have docked to it, and immediately accessible, space tug vehicles with crew compartments, propulsion modules, and instrument units capable of housing and supporting the entire remaining station crew.
6. Each orbiting lunar station mission sequence shall be planned such that a backup or emergency source of power, life support, and communication capability is available at all times so that following loss of a primary source the crew can proceed to a safe haven unassisted or await rescue, whichever time is greater.
7. Cabin atmosphere in an orbiting lunar station shall be monitored at all times to detect contaminants such as solid particles, excessive CO₂, vaporized chemicals, and permit correction action to be taken before illness, incapacitation, or oxygen deprivation can occur.
8. Each orbiting lunar station shall provide oxygen masks and emergency pressure garments at each crew station, pressure suits and PLSS units for each crew member, and immediate use of these or escape to a separate compartment following explosion, fire, loss of pressure, or detection of contaminants in the atmosphere.

9. High-pressure gas storage bottles, pyrotechnics, and hazardous experimental devices shall be separated from the main cabin of an orbiting lunar station and from initial subsystems components by enclosing in compartments vented to space and in structures designed to help control an explosion of fire.
10. Pressures in high-pressure storage vessels shall be monitored to provide warning of an impending explosion, and procedures shall be developed to correct potential hazards so detected.
11. Where multiple pressure compartments are provided in a system, crew members shall not all occupy one compartment at one time.
12. Provision shall be made in orbiting lunar station design for quickly sealing each pressurized compartment separately, and then remotely exhausting the atmosphere to extinguish a fire. (See note Page 2-26)
13. Fire extinguishers shall be provided in each pressurized compartment of manned vehicles.
14. Attitude control thrusters and electronics for space vehicles shall be designed to fail "off" to prevent excessive angular rates from developing.
15. Space vehicles shall be provided with backup or emergency attitude stabilization system to arrest tumbling and allow repair or capture by an assisting vehicle.
16. Space tug vehicles docked to an orbiting lunar station shall be capable of providing emergency attitude stabilization for the entire system.

HAZARD STUDY 5

ASSEMBLY OF ORBITING LUNAR STATION ELEMENTS IN LUNAR ORBIT

INTRODUCTION AND DISCUSSION

In the event that a capability to transport a fully assembled orbiting station to lunar orbit is not developed, assembly of station modules in lunar orbit will be required. It is believed that such orbital assembly will consist of docking and coupling of modules, aided by manned space tugs in a manner little different from normal operations with tugs, crew compartments, cargo modules, and propellant modules. Major appendages such as solar arrays, antennae, and scientific experiment booms will be deployed by mechanical means not requiring EVA.

No major hazards unique to orbital assembly of an orbiting lunar station are foreseen for the conditions described above.

SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. Orbital assembly, if required, shall be planned to use normal docking and coupling procedures and devices developed for operational use with tugs, crew compartments, cargo modules and propellant modules.
2. Major appendages for an orbiting lunar station, including solar arrays, antennae, scientific experiment booms, and other, shall be deployed by means not requiring EVA.

HAZARD STUDY 6

CREW INGRESS/EGRESS FOR SPACECRAFT IN LUNAR ORBIT

INTRODUCTION

This study is concerned with crew ingress/egress for all spacecraft in lunar orbit and for crew members in a shirtsleeve or a spacesuit mode. However, the actual EVA mode of operations by any crew member is reserved for discussion in Hazard Study 7. Dysbarism is discussed in Hazard Study 39.

In the course of events in lunar orbit, crew members will accomplish various transfers between spacecraft; such transfers will include movement between:

1. The lunar space station and various tugs
2. The crew module leaving or arriving on a PTV and the lunar station
3. One tug and another
4. The lunar space station and any of its docked cargo or experiment modules

ASSUMPTIONS

1. All crew members engaged in planned EVA will do so through the use of an airlock.
2. Airlocks are constructed with equipment to supply environmental control either through a space suit loop or to a crew member in shirtsleeves.
3. Each airlock will accommodate a minimum of two crew members.
4. Ingress/egress hatches are designed to be jam-proof, quick opening, and to open in a direction judged optimum for safety for the specific configurations.

MAJOR HAZARDS

1. Crew member(s) are isolated outside of an airlock, by virtue of a malfunctioning hatch, while in a space suit and returning from EVA operations.

2. A crew member is unable to leave the spacecraft through an airlock when required for his own safety.
3. A crew member in a shirtsleeve mode is 'trapped' in an airlock.

ANALYSIS OF THE IDENTIFIED HAZARDS

Effects of Hazard 1, EVA Astronaut Isolated outside Spacecraft

1. Since the astronaut(s) are in the process of returning from EVA their consumables will be largely depleted, therefore, they face the threat of asphyxiation unless oxygen can be gotten to them. Temperature control mechanisms and power are also nearly depleted so that the qualities of environmental control in toto deteriorate as spacecraft entry is prolonged.

Corrective Measures for Hazard 1

Preventive measures:

1. Provision should be made for supplying all of the necessities for environmental control by plug-ins outside of the airlock including oxygen supplies, temperature control, power, humidity control, and contaminant control. Communications facilities should be supplied also. The astronauts should have the option of controlling these supplies themselves in addition to such control as may be exerted by the spacecraft crew. These supplies should be tapped from the spacecraft's main ECS to cover the case of a prolonged stay outside. It is recognized that the additional outlets represent potential leak paths.
2. A second airlock should be available on the orbiting lunar station for use by crews deployed in EVA operations.
3. It is suggested that the outer hatch be kept open while a crew member is on EVA.

Remedial measures:

1. Provide outside assistance to open the malfunctioning hatch or rescue the isolated crewman. The hatch should be operable from either side.

Escape/Rescue Requirements for Hazard 1

1. The astronauts must be aided in getting into their spacecraft through the malfunctioned hatch or be rescued by another vehicle. The outer hatch may be forced from the inside by a suited crew member.
2. If assistance is not available, the astronauts will have to get to another airlock or to a different spacecraft.

Effects of Hazard 2, Astronaut Trapped in Spacecraft

1. Because emergency EVA is postponed the crew member's life is endangered by some undefined condition on the spacecraft.
2. If a crewman is attempting to transfer from a spacecraft for rescue operations then such rescue is endangered.

Corrective Measures for Hazard 2

Preventive measures:

1. It is recommended that the lunar space station have a minimum of two airlocks in order that members of its crew may have alternate paths to leave the spacecraft.
2. It is also suggested that space tug design be examined to ascertain the desirability, as well as the cost in volume and weight, of having two airlocks for crew use during tug activities.

Remedial Measures:

1. Provide equipment and procedures for forced exit as a part of the spacecraft or station design.

Effects of Hazard 3, Astronaut Trapped in Airlock

1. A crewman working in shirtsleeves in an airlock will be endangered should the inner hatch fail to open. Life support supplies in the airlock may be limited, and access from outside cannot be gained without evacuating the airlock.

Corrective Measures for Hazard 3

Preventive measures:

1. Provision should be made for supplying all of the necessities for environmental control within the airlock including oxygen, power, temperature and humidity control, and contaminant control. A communications loop will also be required. The crew in the airlock should have the option of controlling their immediate needs. ECS supplies should be gotten from the spacecraft's main ECS to cover the case of a prolonged stay in the airlock. All airlock hatches are expected to be open when crew members in a shirtsleeve mode are moving between a pair of docked spacecraft. Such hatches are all kept open until transfer has been completed.
2. It is suggested that crew members in a shirtsleeve mode do not engage in airlock activity that requires working with the inner hatch closed.
3. If a crew member must work in an airlock with both inner and outer hatches closed it is suggested that pressure suit and PLSS be available in case EVA exit is required.

Remedial measures:

1. Provide equipment and procedures for forced opening of an inner hatch from either side.

2. Provide rescue through the outer hatch to a docked, shirtsleeve environment, vehicle.

Escape/Rescue Requirements for Hazard 3

With assistance: The 'trapped crew members will have to be rescued through the efforts of other members of their crew or another spacecraft will have to be used in a rescue.

Without assistance: The 'trapped' crew will have to force the hatch to "escape" to the main cabin.

Further Recommendations

It is recommended that studies be conducted to determine the necessary numbers of airlocks for each of the spacecraft and vehicles in the entire lunar complex.

HAZARD STUDY 6
SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. Each orbiting lunar station shall have a minimum of two airlocks to use for EVA purposes.
2. An outer hatch shall remain open on an orbiting lunar station while crewmen are on EVA.
3. Design of hatches shall include provision for forced opening from either side.
4. The ECS operations for airlocks shall be supported by the spacecraft's main ECS and have emergency separate environmental controls as well. Each airlock should have self-contained regulatory controls both for ECS supplied from the main cabin supply and for airlock emergency ECS.
5. Crew members in shirtsleeves should not carry on airlock activities with the inner hatch closed. If unavoidable, then pressure suits and PLSS's should be available in the airlock.
6. All airlocks shall be connected to the spacecraft communications loop. Moreover, it should be possible to contact other members of the lunar complex using airlock communications.

HAZARD STUDY 7

ORBITAL EXTRA VEHICULAR ACTIVITY (EVA)

INTRODUCTION

Commensurate with missions of long duration and the choice of hardware with inherent high reliability, characterized by either designed-in multiple redundancy or selection of components with very long mean-time-before-failure MTBF, strong implications of high cost exist. Alternatively, to obviate the high cost but still retain high reliability the use of man in the maintenance/repair loop should be instituted. As the mission lifetime increases without end, as in the OLS-lunar base, the use of man in this maintenance/repair cycle becomes mandatory.

Tasks will occur for long-lived spacecraft that require the presence of man outside the spacecraft. Because the OLS lifetime will be measured in years, it is reasonable to expect a variety of EVA for purposes of meteoroid puncture repair, replacement of RCS thrusters and for general inspection and preventive maintenance activity in order to assure the crew of the general integrity of their spacecraft during the time the lunar space station orbits the Moon. This activity implies innumerable extravehicular engineering tasks throughout the OLS-lunar base program. Manned 'locomotion', maneuvering, materiel handling, maintenance and repair, alignment, and assembly-aid constitute integral parts of the EVA tasks. It is reasonable to state that without the aid of EVA the OLS-lunar base program would become much more complex and therefore more expensive and less reliable.

ASSUMPTIONS

1. EVA will be required in the OLS-lunar base program.
2. EVA typical tasks are:
 - a. Replacement of the RCS nozzles on the OLS
 - b. Performing maintenance on antennas

- c. Repairing meteoroid damage externally (separate from whatever is repaired internally)
- d. Replacing sections of the environmental control system radiators
- e. Servicing unmanned lunar satellites under the jurisdiction of the OLS
- f. Performing some assembly and disassembly functions at the propellant farm in lunar orbit
- g. Obtaining close-up photographs of external damage or other phenomena which have an impact on the operation/integrity of the OLS
- 3. Methods of providing ECS and communications will not include using long umbilicals if the EVA crew member is away from the OLS.
- 4. If EVA is required for some task on the external surface of the OLS then the crew member will have three options:
 - a. Connecting a short umbilical to an external plug built into the station surface, or
 - b. Using a PLSS
 - c. Using a cherry-picker like device (described later in this discussion) which obviates the need for a PLSS or a long, free-floating umbilical.

THE MAJOR HAZARDS

- 1. Malfunction of oxygen supply.
- 2. Communications malfunction.
- 3. AMU malfunction leading to loss of attitude control.
- 4. Overburn of propulsion unit leading to stranded astronaut and/or excess ΔV separating astronaut from vicinity of OLS or heading him into a collision with OLS or other spacecraft in vicinity.
- 5. Illness while in EVA mode leading to vomiting, etc.
- 6. Loss of electrical power.
- 7. Exposure to excessive radiation.

ANALYSIS OF THE IDENTIFIED HAZARDS

Effects of Hazard 1, Oxygen Supply Loss

It is conceivable that the crew member operating in an EVA mode may be so interested in his task that he neglects to monitor his oxygen supply and runs out of oxygen. Alternately, his oxygen supply may malfunction through hardware failure. This failure may be internal - a component failure, or external - failure due to meteoroid strike.

Lack of oxygen for ~ 20 seconds results in loss of consciousness, and lack of oxygen for 3 minutes results in irreparable damage, and 5 minutes denial results in death.

Corrective Measures for Hazard 1

In addition to his normal oxygen supply the astronaut should have an emergency, 30 minute, independent supply. Initiation of use of that supply should set off an alarm both at the astronaut and on the display board by which he is monitored, and makes return to the cabin of his spacecraft (tug, OLS, etc.) mandatory and immediate.

If the EVA is on the external surface of a spacecraft, particularly the OLS, then a relatively short umbilical from the astronaut should be plugged into an external plug on the spacecraft surface for an oxygen supply.

Escape/Rescue Requirements for Hazard 1

If the emergency oxygen supply suffices for return to a safe haven then no requirements for rescue exist. The astronaut has escaped from his dangerous situation. If for some reason his emergency oxygen is insufficient to permit safe return then rescue must be initiated at once. Thirdly, one astronaut should be able to plug into the ECS of a co-working 'partner' who

is in an EVA mode or vice-versa. The latter situation should make return to a spacecraft cabin mandatory and immediate. ECS plugs should be available on the surface of every spacecraft used by man so that an astronaut in EVA could plug into such systems using a short umbilical; from this position he should be safe until rescue is completed.

Effects of Hazard 2, Communications Malfunction

By equipment failure, by meteoroid strike or by loss of electrical power a communication malfunction and loss can occur. Equipment failure means the failure of any of the hardware in the communications subsystem which immediately leads to loss of communications.

Loss of communications leads to a lack of information exchange between EVA astronaut and the spacecraft from which he is operating. The information includes both voice communication and monitoring of the vital signs (life functions) of the astronaut, thus knowledge about astronaut well-being is not constantly available.

Corrective Measures for Hazard 2

Communications loss leads to mandatory and immediate return to spacecraft for EVA astronaut. Circuit failure, either voice or monitoring, should set off alarm for EVA astronaut, and alarm operation should be independent of communications circuit operation. Communications for an EVA astronaut should be an essentially continuous activity while he is outside the spacecraft. At the very least a communications check should be made every 5 minutes.

Escape/Rescue Requirements for Hazard 2

Primary measure is for EVA astronaut and monitoring spacecraft to recognize lack of communications and to get a signal to the astronaut to tell him to

return to his spacecraft immediately. Such a signal could include the use of flashing beacon aimed at his helmet or a tug on his umbilical if he is attached to the spacecraft. If astronaut's alarm does not work then another astronaut is required to go out and get the crew member whose system has failed.

Effects of Hazard 3, AMU Malfunction

Failure of an attitude control thruster to stop firing when all other thrusters have stopped or, incorrect, unbalanced thrusting will lead to loss of attitude control. Loss of attitude control leads to uncontrolled tumbling of the astronaut, disorientation, nausea and illness (vomiting). Illness, nausea and vomiting will not be dealt with here, they are discussed in Hazard Study 35. Prolonged tumbling at rates of 300 degrees/second will lead to unconsciousness and eventually death.

Corrective Measures for Hazard 3

The astronaut should have a method of shutting down any 'runaway' thruster prior to reaching dangerous rate limits. He should have control of each thruster separately or any combination in concert to null out all tumbling. Attitude control thrusters should be disabled whenever EVA astronaut is tethered or is moving about on the surface of any spacecraft using handrails, etc. Astronaut should be able to disable thrusters by choice no matter what his location.

Escape/Rescue Requirements for Hazard 3

Recovery methods for an astronaut with attitude control loss are essentially the same as the capabilities listed in the corrective measures. If, however, after shutting down attitude control this function is still necessary for a return to a safe haven, then the EVA astronaut will need assistance from outside in the form of rescue.

Effects of Hazard 4, Propulsion Overburn

The AMU (astronaut maneuvering unit) has frequently been suggested as a means of propelling an EVA astronaut from one location to another during the course of space activity. One system uses a hot gas and can supply a ΔV to the astronaut of at least several tens of ft/sec. Should the system fail and continue to operate after a command to cease is instituted, the astronaut will be propelled past his destination at a rate that could easily exceed 20 ft/sec if he does not steer himself to nullify this effect.

The astronaut will rapidly extend his distance from his intended destination. His capability to return unassisted is made exceedingly difficult, if not impossible, since most, or all, of his propellant will be expended. A ΔV of 20 ft/sec will carry him, in 15 minutes, 18,000 feet from his location at the burn initiation if he does not maneuver. Implications then follow concerning his oxygen supply as well as his propulsion capability.

Corrective Measures for Hazard 4

The EVA astronaut must have positive capability to shut down thrusters, which may be accomplished by cutting off propellant flow, or by cutting off electrical power to the AMU. This cutoff should not affect life support.

Alternately, with judicious use of his attitude control system, the astronaut could stay in a desired vicinity by steering himself. Thus, a propulsion overburn may be controlled to the extent of not changing his location by any significant amount.

Escape/Rescue Requirements for Hazard 4

The EVA astronaut must have the capability (as a last resort) to steer himself to remain in the vicinity of his spacecraft in the event of propulsion shutdown failure. A rescue mission will be required if the overburn is permitted to drive the EVA astronaut away from his normal work area.

Hazard 5, Illness during EVA, is discussed in detail in Hazard Study 35.

Effects of Hazard 6, Loss of Electrical Power

Electrical power may be lost by the EVA astronaut through battery failure or through failure of other components in the electrical power supply circuit. Either of these failures may occur because of failure in the hardware itself or through the mechanism of an outside agent; e.g., a meteoroid strike. An EVA astronaut using an umbilical will have power supplied by his 'mother' spacecraft, and a battery pack only for emergency use should the umbilical power line fail. Failure of electrical power shuts down all EVA subsystems. Communications, temperature control, automated oxygen flow and atmosphere cleansing, and propulsion capability are all lost for the astronaut.

Corrective Measures for Hazard 6

A separate pack of batteries, for emergency use in the event of prime power pack failure, is required for the EVA astronaut.

If the astronaut is working as part of a team he should have an umbilical to plug into the power system of a fellow astronaut and vice-versa. In the event of working on the external surface of a spacecraft, and tethered to that surface, the astronaut should have the opportunity to plug into external power-source plugs located on the surface of all spacecraft including the OLS. Such plugs should also make available life support supplies and communications.

The EVA astronaut must have:

1. A totally independent communications alarm (May-day signal) that will activate if his normal electrical power fails, and

2. a separate battery pack to power his communications alarm and his propulsion system for a minimum of ten minutes to permit return to 'mother' spacecraft,
3. a manual oxygen flow control in the event of power failure,
4. a suit designed such that loss of electrical power will not cause temperature in the suit to rise above 90°F for 30 minutes after power loss occurs.
5. it should be possible for one astronaut to plug into the life support, power, and communications of a fellow astronaut in the event of malfunction. The buddy system in EVA activity is strongly recommended.

Escape/Rescue Requirements for Hazard 6

1. His electrical power fails and the EVA astronaut now separated from his mother spacecraft must be rescued within a time bounded by his manually operated emergency oxygen supply which is 30 minutes.
2. The EVA astronaut becomes 'entangled' in some large structure he is assembling and must be extricated with the use of outside aid, and
 - a. He has a plentiful supply of consumables to that rescue must be completed within 3-4 hours. Also, he is not injured in this instance, or
 - b. He is injured and must be rescued post-haste.
3. The EVA astronaut's propulsion fails "off"; he is not on an umbilical and is unable to return to his spacecraft unaided. His consumables supplies are:
 - a. In good order and plentiful.
 - b. In good order but limited.
4. The EVA astronaut's communications have failed; he is unaware of this since he is busy at his assigned task away from his spacecraft. Regular voice contact is mandatory, therefore, another astronaut must be sent out to bring back the first astronaut. If the astronaut is close to his monitoring spacecraft it could be possible to signal him with a flashing beacon; he might even wear such a beacon and have it activated by his

governing spacecraft. Should continual communications be mandatory then the astronaut will quickly be aware of a failure by lack of response from his monitor.

GENERAL COMMENTS

All of the numbers used in the following candidates for safety guidelines represent current best engineering judgment. Further analysis is recommended.

An alternate and suggested method for EVA tasks - as opposed to long umbilicals and/or free flying astronauts - encompasses the use of a cherry-picker-like device attached to a tug, see Fig. 1. The cherry-picker is composed of a cradle and attached cages to hold the astronaut and parts and tools, a wristlike joint which is an attach point for the cradle and one-half the cherry-picker arm, the second-half of the arm is also attached to the tug and at this attach point at least one degree of rotational freedom is available. The entire cherry-picker arm folds into a longitudinal slot built into the exterior of the tug. When folded, the cradle is at the tug airlock. The astronaut is tethered in the cradle and is free above his hips to handle tools and parts and to perform a very wide variety of tasks. Umbilicals from the tug to the astronaut may be run along the cherry-picker arm. An emergency power and ECS supply is fixed to the cradle and plugged into the astronaut. It is activated at the turn of a switch. Such a device, when and where available, would obviate most of the proposed safety guidelines and the various hardware/cost penalties associated with implementing the guidelines. The safety of the EVA astronaut is vastly improved by virtue of use of the cherry-picker. His permissible EVA task time will be much more fruitfully used, since he is constantly tethered comfortably, works more efficiently, and knows he is safe.

STATION OR STRUCTURE

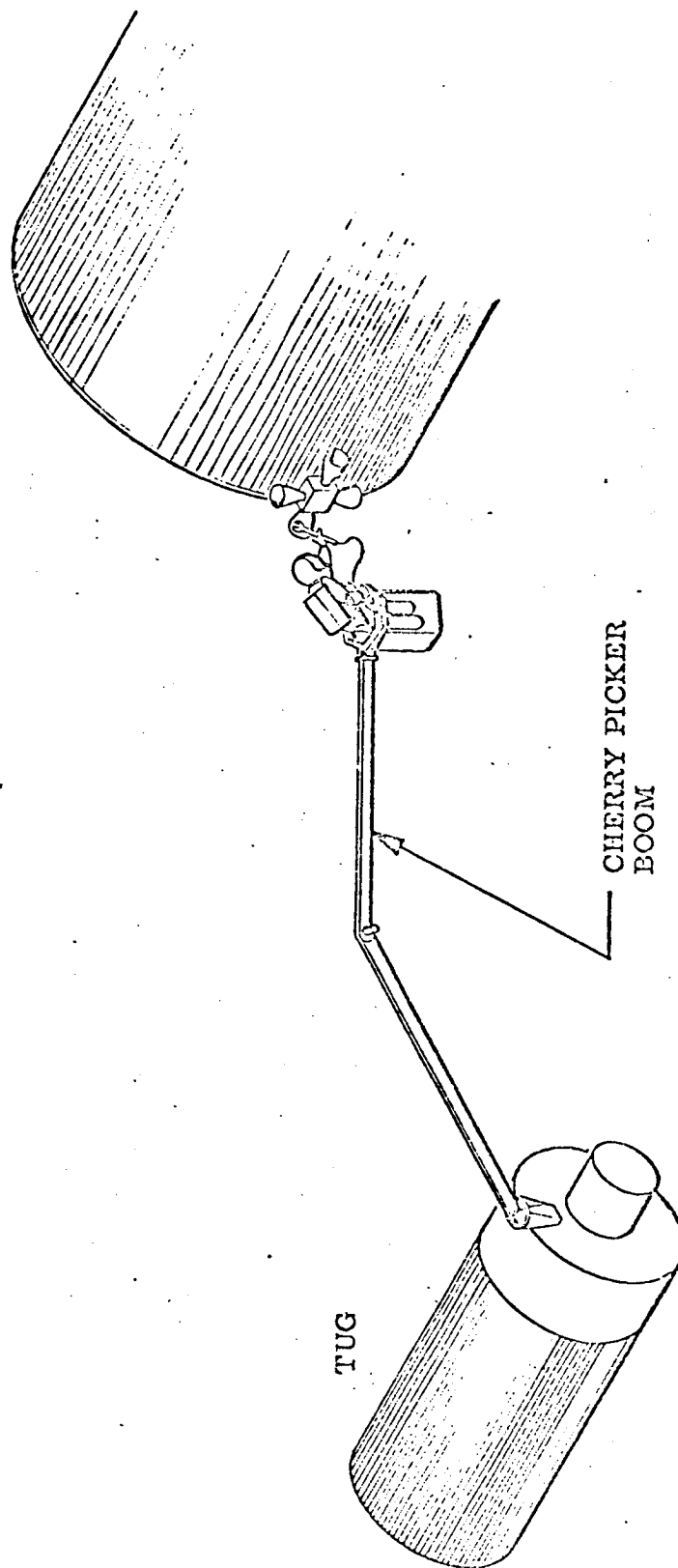


Fig. 1 EVA Cherry Picker Concept

HAZARD STUDY 7
SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. In the event of loss of primary electrical power by an orbital EVA astronaut, an emergency battery pack shall supply power to
 - a. run the astronaut propulsion unit for a minimum of 10 minutes
 - b. keep suit temperature below 90°F for 30 minutes
 - c. run a May-day communications alarm for one hour
 - d. run a flashing light (wattage to be determined) for at least one hour
2. EVA astronaut propulsion must fail "off".
3. An EVA astronaut attitude control subsystem shall be capable of being used to keep the astronaut in the vicinity of his spacecraft in the event of a runaway propulsion system.
4. An astronaut shall be capable of disabling any or all AMU attitude control thrusters at all times.
5. AMU attitude control thrusters for an EVA astronaut shall be disabled whenever he is tethered and not translating. Tethers must be impervious to damage from hot gas or other AMU exhaust products.
6. An EVA astronaut shall have a communications (May-day) alarm, self-powered, and activated automatically should his communications subsystem or his electrical power subsystem fail.
7. A communications failure shall lead to an immediate and mandatory return to the EVA astronaut's spacecraft.
8. All EVA astronauts shall carry a 30-minute emergency oxygen supply to be used only in the event of failure of the main oxygen supply. Switchovers may be manual or automatic, but a signal of automatic switchover must be provided the astronaut.
9. The emergency oxygen supply feed shall be capable of manual control by an EVA astronaut.
10. An EVA astronaut using his emergency oxygen supply shall have an immediate and mandatory requirement to return to his spacecraft.

11. All spacecraft shall have plugs strategically located on their surfaces so that an EVA astronaut can attach umbilicals for oxygen, electrical power, and communications.
12. All spacecraft shall have hand-holds and tethering places strategically located on their surfaces so that an EVA astronaut may use these in the course of those tasks in which he is located on the spacecraft surface.
13. The buddy system - or presence of a safety man - is mandatory when EVA astronauts are assigned tasks in which they are operating detached from the spacecraft or station.
14. The buddy system - or presence of a safety man - is desirable for an EVA astronaut assigned to a task on the surface of a spacecraft to which he is tethered.
15. EVA should be viewed as the method to accomplish tasks outside of spacecraft when good judgment by the mission commander (in some cases perhaps, with Earth-control concurrence) deems it useful.
16. Untethered EVA should be prohibited until an astronaut maneuvering unit (AMU) is developed to the extent of being very reliable.

HAZARD STUDY 8

SATELLITE DEPLOYMENT

INTRODUCTION

The deployment of satellites in lunar orbit for scientific purposes is a planned activity to be accomplished on-board an orbiting lunar station (OLS). The handling, check out, launching and recovery of these units entails certain potential hazards to the personnel involved. This study area considers the hazards aspects of satellite deployment activities.

ASSUMPTIONS

1. Freeflying satellites (when docked to an OLS) will be docked to the experiments airlock docking subsystem and not to OLS docking ports. (Ref.1)
2. Maintenance and repair of experiment satellites will be performed in an experiments airlock, which will be part of the OLS experiments Laboratory. (Ref.1)
3. The satellites to be launched from an OLS may have propulsion systems for delivery of instrument packages to orbits unlike that of the OLS. (Ref. 1 and 2)
4. Most satellites will have stabilization/propulsion systems for orientation/stabilization or station keeping purposes.
5. Shirtsleeve environment for satellite servicing is an OLS operational requirement. (Ref. 1)

THE MAJOR HAZARDS

Hazards considered to be significant are:

1. Liquid propellant spillage
2. Liquid or solid propellant ignition/detonation
3. Electrical fire in experiment airlock (satellite or checkout equipment)
4. Satellite collision with OLS during capture maneuver

ANALYSIS OF IDENTIFIED HAZARDS

Effects of Hazard 1, Liquid Propellant Spillage

The replenishment or initial filling of satellite propellant tankage requires manual connection of transfer hoses or pipes. Any misalignment, failure to tighten adequately, or entrapment of fuel or oxidizer in quick disconnect fitting results in leakage and/or spillage of hazardous fluids.

1. The introduction of even small quantities of corrosive or explosive oxidizer, hydrocarbon fuel or some of the more exotic, storable mono-propellants into the airlock atmosphere presents the following hazards:
 - a. Toxic material concentrations
 - b. Creation of explosive atmosphere
 - c. Potential fire hazard
 - d. Corrosion of OLS structural materials
 - e. Potential rapid oxidation of structural materials and/or metal fire involving thin structural OLS segments.
2. Spillage in zero-g could permit 360° dispersal of active fluid to all parts of compartment as well as permitting ingestion by crewmen. The ingestion of fuel or oxidizer into the air purification system could yield a disastrous situation for the entire OLS section serviced by the purification system.

Effects of Hazard 2, Propellant Ignition/Detonation

The servicing of satellites will involve the installation and removal of propulsion components in the satellites. Thus failure to purge fuel and oxidizer systems thoroughly could result in fluid release during disassembly with resulting auto-ignition or detonation. Similarly the installation of solid propellant packages can involve accidental ignition and/or grain explosion under certain circumstances.

The sudden ignition or detonation of liquid or solid propellants within the confines of the experiment airlock is certain to inflict injury upon the

crewmembers involved, even if they are garbed in protective clothing. Further, the generation of gases involved is quite likely to violate the integrity of the airlock compartment and either open it to space vacuum, or to other compartments of the OLS, thus propagating the hazard by exposing other crewmembers. Conceivably the pressure surges could open both inner and outer seams causing depressurization of a large segment of the OLS.

Corrective Measures for Hazards 1 and 2

Preventive measures:

1. Refueling of satellites - Provide a design which accepts prepackaged (precharged) fuel or oxidizer containers. Containers should have built-in check valves which open only after connection is made and final torque-down is accomplished.
2. Provide a satellite propulsion system design which can be totally blown down with small amount of nitrogen which vents overboard through a disposable neutralizing trap. Provide a vacuum line to the disconnect area so that vapors and fluid droplets are swept out to space.
3. Provide solid propellant cartridge modules as complete replaceable components such that installation is safe with no-fire condition until the satellite is armed just prior to deployment (when airlock is open to space) or outside the OLS.
4. As an alternate to 1 and 3 above, provide a high strength closed chamber, mounted on an OLS wall with a blow-out door, in which satellites can be serviced using reinforced arm gloves or a remote manipulator. (Requires spare blow-out doors). A hangar could be used for this function with tethered crew members in soft suits while servicing the satellites.
5. All electrical equipment should be properly grounded to ensure that no accidental electrical discharge occurs involving satellites or servicing equipment.

Remedial Measures:

1. Provide emergency lightweight masks with remote air supply as remedial measure for toxic fumes.

2. Provide warning instrumentation and sensors to detect low levels of oxidizers and fuel materials to be used in satellites.

Effects of Hazard 3, Electrical fire in Experiment Airlock

Electrical fires in the satellite circuiting or test and checkout circuiting may result from a number of causes such as shorts, circuit overloads, damaged parts, simple random failures or human errors in the test and checkout setup or operations.

The effects of an electrical fire in the test and checkout of a satellite will range from simple circuit damage to loss of the satellite and may include activation of the pyrotechnics, ignition and/or detonation of propellants with subsequent major fire or overpressure generation. Thus a simple fire may result in loss of the experiment airlock area and damage to the major OLS structure. An electrical fire in the presence of propellant vapors would lead to the production of various toxic gases which in turn could penetrate the environmental control system.

Corrective Measures for Hazard 3

Preventive Measures:

1. Test and checkout of satellites shall be conducted for the major systems while the unit is unfueled.
2. Final checkout shall be conducted remotely when airlock is open to space vacuum.
3. Use wiring insulation that does not yield toxic gases in combustion.

Remedial Measures:

1. Use gas mask if toxic gases appear.
2. Have vent to space if fire occurs, while crew uses oxygen masks.

Effects of Hazard 4, Satellite Collision with OLS

The recapture of a satellite (by an OLS) upon completion of its mission implies that the satellite can be maneuvered so as to return to the OLS vicinity and into the open airlock. The degree of design sophistication required for this ambitious undertaking is thought to be somewhat beyond current state-of-the-art. However, granting that it is possible for a large relatively passive station like the OLS to serve as the target into which a satellite must be maneuvered, then a recognizable hazard is the collision of the satellite with the OLS if its approach velocity were too great.

Effects include:

1. Probable loss or destruction of the satellite.
2. Possible damage to OLS structures from mass of satellite (velocity dependent).
3. Possible damage to OLS due to detonation of satellite from propellant mixing and ignition upon impact.
4. Decompression of OLS if satellite penetrates OLS via windowport or thin structure area.

Corrective Measures for Hazard 4

Preventive Measures:

The capture of satellite vehicles at the completion of its mission can best be accomplished via a tug vehicle which is specifically equipped to snare, grab, enclose, or otherwise latch onto the satellite. It is expected that the satellite orbit will be known and its spatial position easily determined by either OLS or tug vehicle. Further, the satellite would have a transponder or beacon for this purpose. Thus a tug could transfer to the orbit at an opportune time and effect the satellite capture, shut it down and return to station at no danger to the OLS.

Escape/Rescue Requirements for Hazards 1 through 4

Such events as fire and propellant detonation or explosion in the experiment servicing area of the OLS will in all probability generate escape and rescue requirements for the personnel involved. The collision of a satellite with the OLS, either as a direct impact or a grazing collision could also generate such requirements. The various aspects of the above hazards have been considered in some detail in the Ref. 1 document.

ADDITIONAL INFORMATION

It is recommended that satellite servicing be conducted in a pressurized hangar separated from the main OLS compartment by an airlock in the general manner planned for the Earth Orbiting Space Base.

SOURCE DATA REFERENCES

1. Orbiting Lunar Station - Phase A Study Final Report - Sec. 1, Objectives and Requirements. MSC-02686, (SD 70-518), dated Oct 1970, North American Rockwell, Space Division, Downey, Calif.
2. Lunar Orbit Stations - Project Description Document, AMPO, MSC, Houston, Texas. Dated April 1970.

HAZARD STUDY 8

SUMMARY OF SAFETY GUIDELINE CANDIDATES

1. Satellite deployment and initiation of operations considered hazardous shall be made ready from a remote location before exposing crewmen to potential hazards.
2. Refueling of satellites shall be accomplished by use of prepackaged fuel and oxidizer container with built-in valves which open only after final installation.
3. Servicing of satellite propulsion shall only be accomplished after thorough system venting and purging.
4. Vacuum venting of immediate area where system piping or tubing is opened shall be accomplished for each system breaching operation involving dangerous liquids or gases.
5. All solid propellant installations shall be designed to accept a complete prepackaged solid propellant module designed to be "no-fire" safe until satellite is armed for deployment.
6. Emergency breathing masks shall be available in the experiment airlock as a quick remedy for atmospheric contamination.
7. Specific warning instrumentation and sensors designed for the satellite propellant fluids to be handled shall be installed in areas where such fluids are to be stored or handled.
8. Automatic fault detection equipment utilization shall be employed as the first step in the test and checkout of satellites. The sudden rise of current above test limit shall cause power cut-off to the test-and-checkout setup as a means of preventing electrical fires.
9. Satellite capture for data return and reuse shall be accomplished via a tug specifically equipped for the task, in order to avoid potential collision problems for the OIS.
10. Careful attention shall be given to the use of non-flammable materials where possible in satellite design.
11. Grounding and arming of explosive and propulsive devices should be accomplished on a satellite after it has been removed from the orbiting lunar station.

HAZARD STUDY 9

NUCLEAR POWER PLANT OPERATION AT AN ORBITING LUNAR STATION

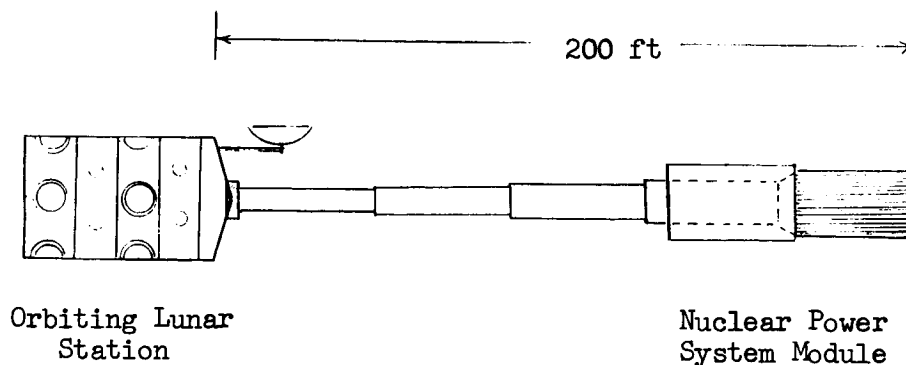
INTRODUCTION

The utilization of nuclear power plant technology for lunar space station application is motivated primarily by the sizable station power requirements and the logistics constraints inherent in the operation of a distant, self-contained facility. The factual recognition of the penalties associated with utilization of the only existing device capable of providing multi-kilowatt electrical power will permit the evolution of a practical, space-operable nuclear power system.

A study is currently being conducted for the NASA (Ref 1) which is intended to provide key nuclear safety design guidelines and overall nuclear hazards identification for space based nuclear electrical power systems. Therefore, this Study Area will only address itself to the major manned lunar exploration operational mission hazards interfaces generated by the space based nuclear power unit.

ASSUMPTIONS

1. The synthesized orbiting lunar station with nuclear reactor power module is assumed to be configured as follows:



2. The operations conducted in and about the orbiting station are the normal planned activities as defined in the lunar exploration program model.
3. The normal planned radiation levels around the nuclear power module are such that the detectable natural space radiation level exceeds normal shielded reactor emitted radiation level.

The primary hazard generators, related to manned operations around a lunar orbiting station equipped with a nuclear power module of the type considered in Ref. 1, are as follows:

1. The recognized major sources of potential radiation leakage associated with the nuclear power module are (Ref. 1):
 - a. Excessive radiation from the reactor and from components located external to the reactor shield
 - b. Released fission products from reactor and primary coolant circuit assembly
2. The interfacing lunar exploration program elements and operations exposed to the potential hazard generators are:
 - a. Orbiting Lunar Station
 - b. Tug Vehicle operations
 - c. Prime Transport Vehicle operations
 - d. Replacement of nuclear fuel or of reactor assembly

THE MAJOR HAZARDS

Primarily, the major hazard which can be generated by a function failure and/or system integrity violation within the nuclear power module, is the exposure of man to excessive amounts of nuclear radiation.

ANALYSIS OF THE IDENTIFIED HAZARD

The routes by which man can be endangered by exposure to excessive radiation from a nuclear power module are essentially direct in nature. The time span over which the exposures can occur are variable and range from a large, high-level pulse resulting from a destructive reactor excursion to a low-level near background exposure resulting from leakage between power system coolant loops or from plate-out of released fission products on the space station exterior. Other typical sources of radiation hazards examined in the Ref. 1 study are given in Tables 1 and 2.

Table 1
NORMAL SOURCES OF RADIATION

		RADIATION SOURCE	RADIATION ARISING FROM
ABOARD SPACE BASE	REACTOR POWER SYSTEM	NORMAL REACTOR RADIATION FIELD	REACTOR AT POWER OR SHUTDOWN
		NORMAL RADIATION FROM PRIMARY LOOP	REACTOR AT POWER OR SHUTDOWN
		NORMAL RADIATION FROM ACTIVATED COMPONENTS	REACTOR AT POWER OR SHUTDOWN
NATURAL ENVIRONMENT		GALACTIC COSMIC RADIATION	DEEP SPACE
		SOLAR RADIATION	SOLAR FLARE

Effects of the Hazard

Pending definition of the radiation "source-term" for a specific reactor and shield configuration to be employed in the nuclear power module, only a general approximation of the hazards effects can be made for the various accident postulations that are within the realm of credibility.

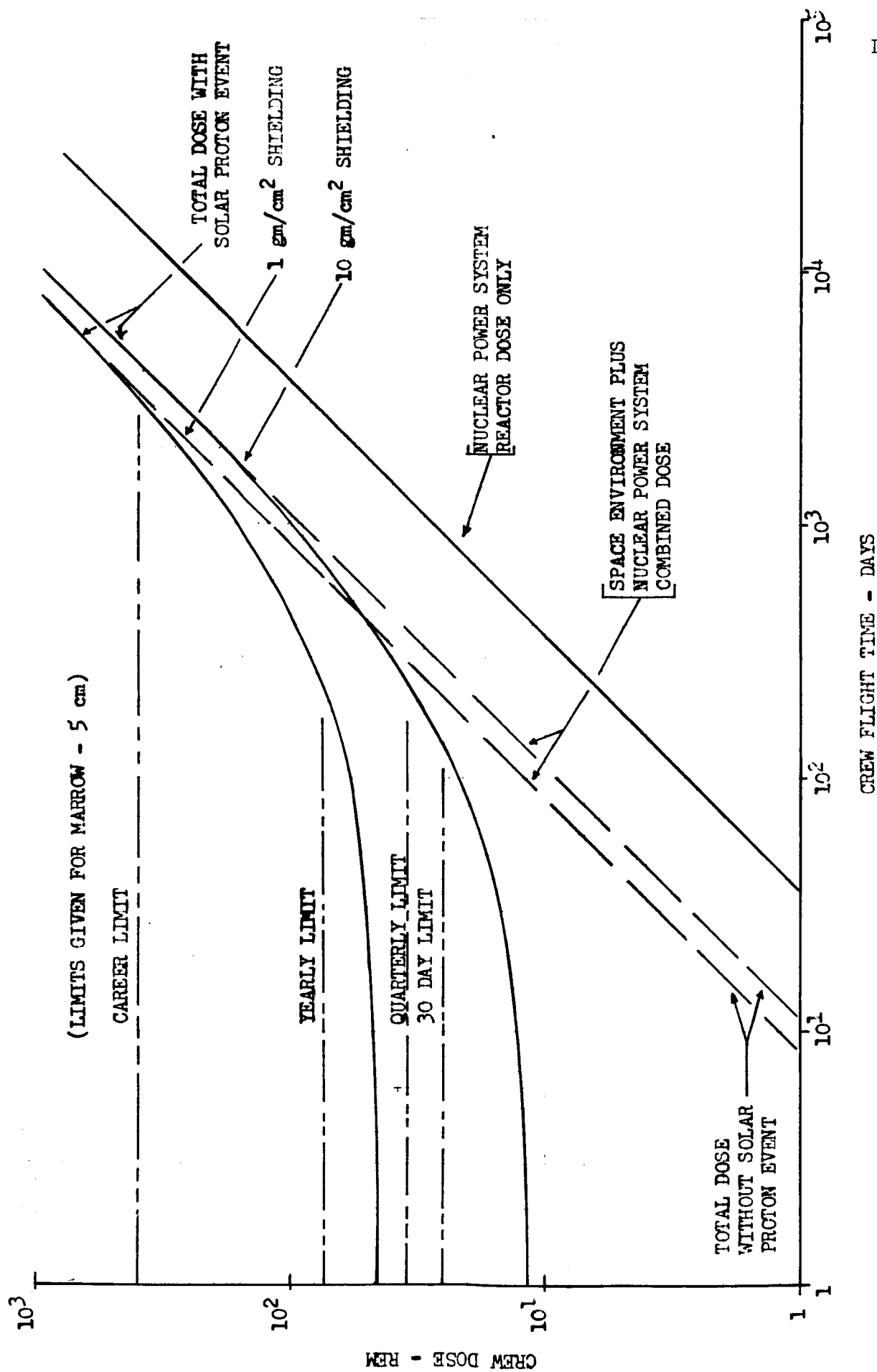
Table 2
ACCIDENT RADIATION SOURCES

		ACCIDENT RADIATION SOURCE	ARISING FROM
ABOARD SPACE BASE	REACTOR POWER SYSTEM	EXCESSIVE RADIATION FROM REACTOR	REACTOR EXCURSION
			OPERATING OR SHUTDOWN, WITH DAMAGED SHIELD
			FAILURE TO SHUTDOWN
		EXCESSIVE RADIATION FROM COMPONENTS LOCATED EXTERNAL TO SHIELD	LEAKAGE BETWEEN POWER SYSTEM LOOPS
			NORMAL REACTOR RADIATION ENVIRONMENT
		RELEASED FISSION PRODUCTS	DESTRUCTIVE REACTOR EXCURSION
			CLAD AND PRIMARY SYSTEM FAILURE
			REACTOR DISASSEMBLY
		RELEASED ACTIVATED MATERIALS • COOLANT • STRUCTURE • FUEL ELEMENTS	DESTRUCTIVE REACTOR EXCURSION
			PRIMARY SYSTEM FAILURES OR LEAKS
			TRITIUM RELEASE FROM SHIELD
ABOARD INTERFACING VEHICLES	NUCLEAR SHUTTLE	EXCESSIVE RADIATION	SHUTTLE COLLIDES WITH BASE
			SHUTTLE PASSES IN CLOSE PROXIMITY TO BASE
		RELEASE OF FISSION PRODUCTS IN ORBIT	SHUTTLE REACTOR EXCURSION
		RELEASE OF RADIOACTIVE DEBRIS IN ORBIT	SHUTTLE EXPLOSIONS
	TUG	EXCESSIVE RADIATION	TUG COLLIDES WITH POWER MODULE
			TUG PASSES IN CLOSE PROXIMITY TO POWER MODULE

A compilation of the anticipated crew allowable exposure limits proposed as a revision to the "Provisional Radiation Dose Limits for Manned Space Flight Beyond Apollo", originally issued by the NASA-Radiation Constraints Panel, is presented in Table 3. This table, taken from Ref. 1, can be utilized to evaluate the relative hazard magnitude associated with credible accidents when the respective "source-terms" for the accident have been defined.

For the nuclear power system employed in the Ref. 1 study the preliminary source-terms for the system are defined. Utilizing this data and the lunar space radiation environment as defined in NASA TM X-53865 (Ref 2) it is possible to compare expected crew dose and exposure limits for an orbiting lunar station equipped with a nuclear power supply module of the type and configuration employed in the Ref. 1 study. These data are presented in Figure 1. Notice that a single solar flare will nearly deplete the crewman's allowable short-time limit if it occurs early in his tour of station duty. For a no-flare condition the crewman would normally receive his largest exposure from the natural space radiation environment.

For a typical case of abnormal station radiation level from a nuclear power system module (without regard to causative factors), the effects of the resulting abnormal ambient radiation level on the crew can be readily assessed. As an example, assume that the ambient level in the station has risen to 20 mr/hr of predominately 1 MEV gamma radiation (which could be typical of a leak between the primary and secondary reactor coolant loops). Assume, also, that a new crew has just started a station duty tour and that the power module is being kept on-line because of critical station requirements for supporting lunar surface base activities. A replacement power module is not available until the next logistics supply mission arrives. The exposure data when plotted as in Figure 2 readily presents the cross-over points for crew dose limits, the ambient gamma dose, the total man-made and space radiation dose, and the impact of a solar event. It can be seen that because of the natural space radiation ambient level and the possible magnitude jump due to a solar event, there is really very little margin for accommodating further radiation



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Fig. 1 Crew Exposure Limits and the Postulated Orbiting Lunar Station Radiation Environment

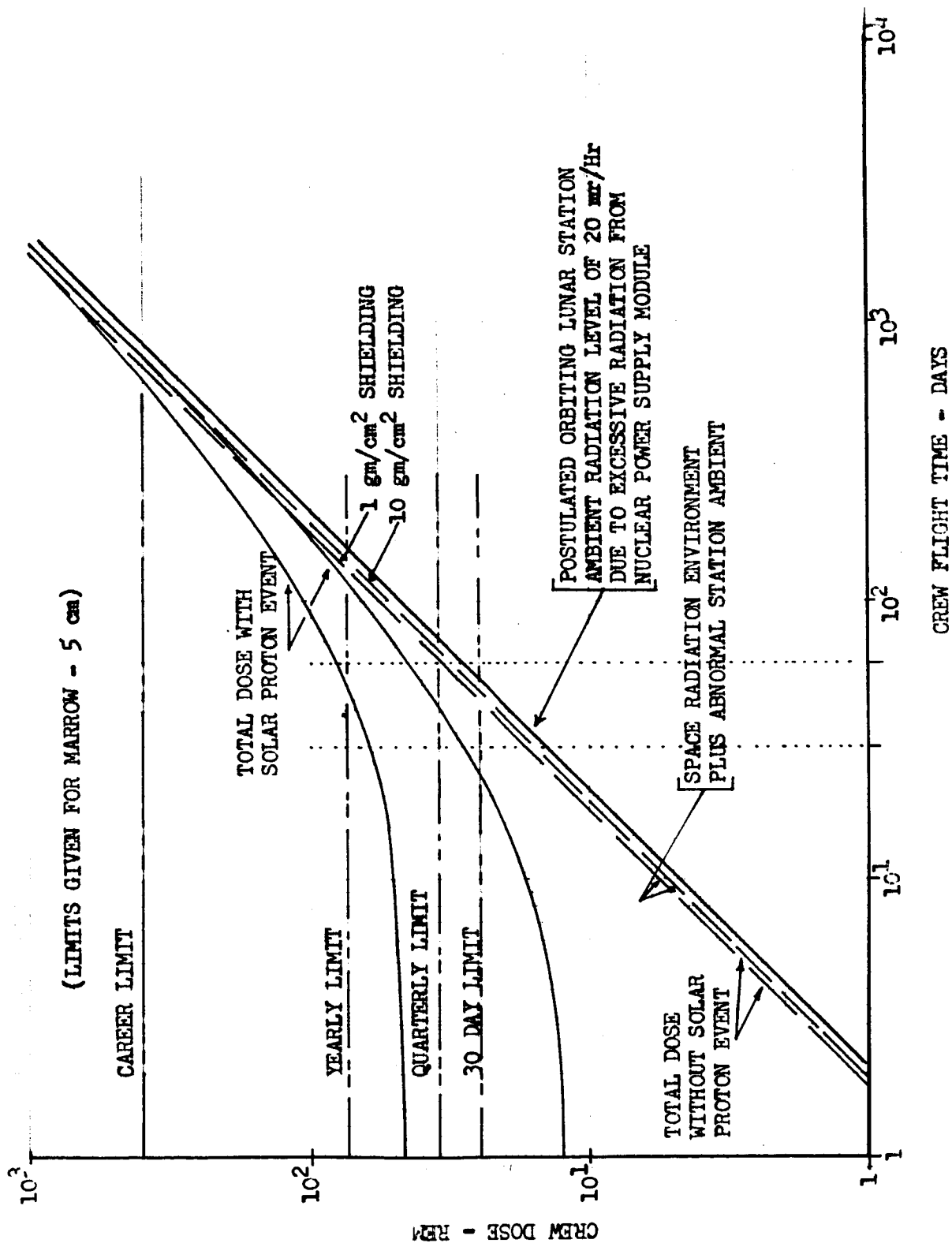


Fig. 2 Crew Exposure Limits and a Postulated Orbiting Lunar Station Abnormal Radiation Environment

Area Depth	1 Yr. Avg. Daily	30 Day	Quarterly	Yearly	Career
Skin (0.1 MM)	0.6	75	105	225	1,200
Eye (3 MM)	0.3	37	52	112	600
Testes (3 CM)	0.1	13	18	38	200
Marrow (5 CM)	0.2	25	35	75	400

TABLE 3 - ANTICIPATED CREW RADIATION LIMITS (rem)
SPACE STATION/BASE, SKYLAB, SHUTTLE

level increases due to additional problems with man-made radiation sources. Should, for instance, the reactor shielding integrity be violated, it is quite possible to have station ambient radiation levels which could range upwards to 10^3 R/hr or better if the reactor viewed the station directly. The credibility of such an event being due, for example, to a meteorite strike is enhanced by recent data indicating the presence of reasonable populations of incoming large meteorites in the lunar vicinity (Reference 3).

For a significant breaching of the reactor shielding, giving rise to high level radiation within the orbiting lunar station, the effects of high level exposure upon the crew are predictable. Data developed in a current NASA Study (Ref. 1) is presented in Figure 3 illustrating the early time effects for acute whole-body exposure resulting from given doses. The chart has been constructed such that an estimate of the capability of an individual crewman as a function of time after exposure can be identified for various radiation doses. The value 50 Rads was taken as the limit below which no debilitating effects would occur. Vomiting was taken as the earliest effect which could incapacitate an individual crewman. In fact, it has been shown that nausea and vomiting occur nearly simultaneously in the onset of radiation sickness (Ref. 1).

The nuclear power module normally would be located some 200 feet from the station, probably on the end of an extendible boom, in order to take advantage of distance as a shielding augmentation factor. A second reason for

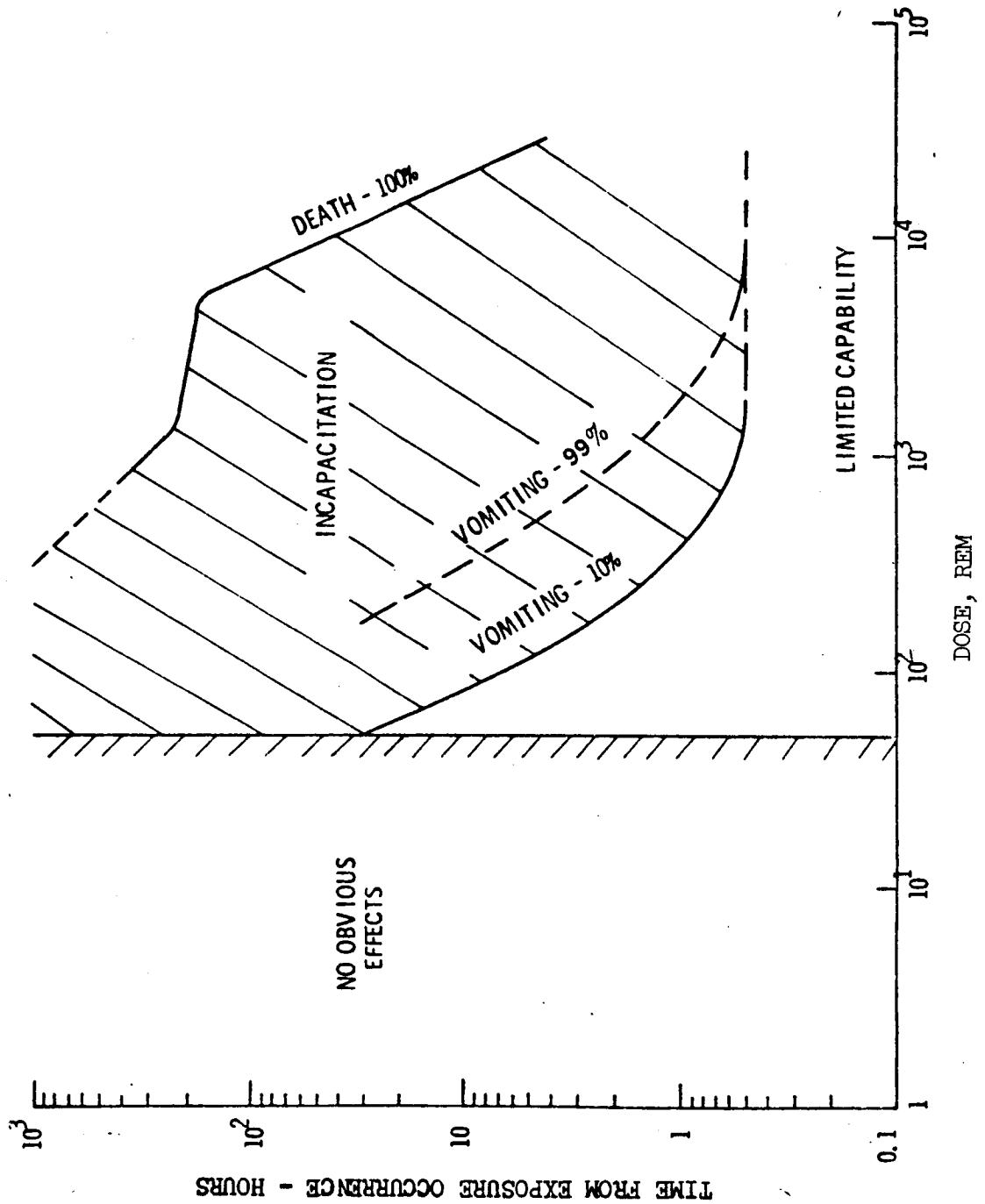


Fig. 3 Early Time Effects - Acute Whole Body Exposure

the distance is the necessity for a very large unobstructed radiator needed to reject excess reactor heat. The extended boom and power module are vulnerable to collision and hence must be considered to be within a restricted operations volume so far as vehicles operating around the station are concerned.

Corrective Measures

Preventive Measures:

1. A nuclear power supply module attached to the orbiting lunar station will necessarily have to be designed to be redundant in all critical control systems and to fail-safe for all critical failure modes.
2. Positive reactor shut-down must be possible under all conditions of mechanical malfunctions, shock, or collision.
3. Reactor-over temperature sensing must cause shut-down prior to thermal degradation of core structure and fuel cladding materials.
4. Reactor shielding integrity must be capable of surviving all credible malfunctions for the shield region which faces and shields the space station. If the shield must vent to preserve its major area integrity, then the venting shall occur in the direction away from the station.
5. The sudden loss of coolant from the primary coolant loop of the reactor must not be possible in less time than required for safe reactor shut-down without melt-down.
6. The reactor shielding shall be designed to be capable of attenuating the radiative energy release of the credible postulated maximum reactor excursion to levels which do not exceed the allowable crew dose (per duty tour) in the space station.
7. Station radiation monitoring instrumentation telemetry data should include one channel which reports ambient radiation levels over the range of from background level to and including ten percent above the maximum level expected in the station from a credible maximum power module reaction excursion. The data thus provided would alert and enable earth-base to rapidly access the incident and render such assistance as necessary or possible in subsequent contingency activity. Data would include dose and dose rate at selected station areas.

8. The reactor system employed shall (as a means of enhancing reliability and useful life in space) be designed to operate at temperatures well within the known capabilities of the proven materials employed in its construction. Design safety margins shall not be less than a factor of 2.0 for the most critical parameter in any given system of subsystem.
9. The power system module design configuration shall be such that it is not possible for a malfunctioning nuclear power system module to inhibit access to, or escape or rescue from, the orbiting lunar station by virtue of direct gamma or neutron radiation beams or fields.
10. Design provision shall be made for detaching an expended or failed nuclear power system module and removing the module from the operational orbit via a tug vehicle (remotely operated if necessary). The disposal of a spent or failed module will be accomplished by procedures that are yet to be determined.
11. Replacement of nuclear fuel or removal of the reactor assembly would have to be provided for by development of techniques for accomplishing these procedures remotely using a tug or other appropriate mechanism. Alternately, a properly shielded tug, operated by crew members and equipped with mechanical manipulators could be used for these functions.

Remedial Measures:

1. The orbiting lunar station, if equipped with a nuclear power supply module, will require on-board capability for emergency treatment of radiation sickness to some limited extent.
2. The Earth-return tug stationed at the lunar orbiting station, must be capable (once activated and separated from the station) of autonomous or Earth-base directed return to Earth orbit, in the instance where an entire station crew has been exposed to radiation levels which will produce incapacitation and serious organic degradation.
3. All crew members will always wear dosimeters, changed at regular intervals so as to keep accurate records of their exposures. Dosimeters will be

mounted at selected points in the OLS (and other spacecraft) and their readings read out on demand by Earth stations, the LSB, orbiting base, and other appropriate spacecraft.

Escape/Rescue Requirements

Since the station would be provided with only a solar-storm shielded area and there is literally no place to retreat to if the station were exposed to large fluxes of high energy gamma and neutron radiation, it is therefore necessary that it be possible to escape from the station if such an event occurred. The station would be equipped with radiation monitoring instrumentation and reactor control equipment as a necessary adjunct to the nuclear power system. Preset alarm levels would warn the crew of the rising radiation level and magnitude of the station radiation emergency. A predetermined level alarm would call for station abandonment to be instituted. The crew would then be required to escape. In the unlikely (but possible) case of a reactor excursion, it is probable that the excursion radiation, impinging on the station, would take the form of a brief but very high level pulse lasting up to one or two minutes followed by a decaying field level as the reactor either shut down or came apart and became noncritical. Such a situation might subject the station to radiation levels which, though brief, could induce subsequent radiation sickness. It is likely that such a situation would require external assistance in the form of rescue and aid.

SOURCE DATA REFERENCES

1. "Space Base Nuclear System Safety Study," First Performance Review, GES-7059, General Electric Co., Nov. 24, 1970.
2. "Natural Environment Criteria for the NASA Space Station Program," 2nd Ed., NASA TM X-53865, MSFC August 20, 1970
3. "Data from U.S. Lunar Station Show Cold, Stiff Moon Regularly Bombarded by Meteorites" by H. M. Schmeck, Jr., New York Times, Nov. 19, 1970.
4. "Radiobiological Factors in Manned Space Flights," W. H. Langham, Ed., National Academy of Sciences, National Research Council, Washington, D. C., (1967).

HAZARD STUDY 9
SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. The radiation shielding incorporated in the nuclear power system module shall be capable of attenuating the radiative energy and particle release, for the postulated maximum credible nuclear source accident, to levels which do not exceed the allowable crew dose, per duty tour, in the orbiting lunar station.
2. The nuclear source shielding integrity shall be such that it will survive, in an integral condition, all assaults resulting from source system mechanical malfunctions, thermal shock, and vehicle collision. Further, the shielding area facing the station shall survive intact the postulated maximum credible nuclear source accident.
3. It shall not be possible for a failed or failing power module to inhibit access to, or escape or rescue from, the orbiting lunar station by reason of direct exposure from gamma or neutron radiation.
4. The nuclear energy source (reactor) shall be capable of positive shut-down in any orientation and under all conditions of mechanical malfunction. The source reactor shall fail-safe to a shut-down condition for all credible nuclear transient conditions.
5. The nuclear power system module shall incorporate design features which permit remote detachment of the module by a tug vehicle for disposal purposes.
6. Flight operations in and around the station shall be constrained to avoid the restricted volume around the power module for a distance determined to be safe.
7. The station telemetry link to Earth shall sample and report the ambient radiation level in the station at any time when the radiation values exceed an established background nominal. The TM shall regularly report dose and dose rate at selected station areas.

8. Replacement of nuclear fuel for the reactor or replacement of the reactor itself will be accomplished using techniques that ensure that the crew members involved do not receive an injurious radiation dose. Actual permissible dose, in the light of the importance of this operation, should be determined.
9. Each crew member shall always wear a dosimeter, changed at regular intervals so as to keep accurate records of radiation exposure. Dosimeter readings will be reported regularly, or on demand, to Earth stations, to the LSB or to other appropriate spacecraft.

HAZARD STUDY 10
LOSS OF PROPULSION AND/OR CONTROL OF A MANNED TUG IN ORBIT

INTRODUCTION

Successful completion of any orbital tug maneuver or transfer operation is dependent on a functioning reaction control system (RCS). This system provides propulsive thrust for minor delta velocity needs and docking maneuvers in addition to attitude control. Where large delta velocities are required, both the primary propulsion system and the RCS must function.

This study examines the hazards resulting from failure of either primary propulsion or RCS or both during lunar orbital operations. Descent to and ascent from the lunar surface are discussed in Hazard Study 16.

ASSUMPTIONS

1. The propulsion/RCS failure does not disturb other subsystems such as life support and communications.
2. The tug carries a crew of two to six men.
3. External assistance may or may not be available.

THE MAJOR HAZARDS

The major hazards identified are:

1. A crew is stranded in lunar orbit in a tug without primary propulsion and/or attitude control, and the vehicle may or may not be tumbling.
2. A tug in lunar orbit with primary propulsion and/or attitude control failed has been rendered unavailable for use in rescue situations.
3. A tug in lunar orbit with primary propulsion failed presents a collision hazard.

ANALYSIS OF IDENTIFIED HAZARDS

Effects of Hazard 1, Stranded Crew

Stranding of a crew in orbit may result in depletion of necessary expendables and in illness or death from excessive tumbling rates or duration.

Corrective Measures for Hazard 1

Preventive measures:

1. Provision of adequate expendables to sustain the crew until remedial measures can be taken. A seven-day supply appears to be adequate for orbital emergencies.
2. Use of RCS thrusters to return to a nearby safe haven, assuming primary propulsion has failed but the RCS is operating and can provide the necessary delta velocity.
3. Provision of a small secondary propulsion system to back-up the primary, and provision of two independent attitude control systems, each having the capability to provide translational delta velocity. The secondary propulsion system is independent of the control systems. It provides translational capability to the limit of main propellant exhaustion and is a small investment for the safety provided.
4. Use of two tugs for initial orbiting lunar station manning operations where outside assistance will not be available in lunar orbit. Because the initial crew is far from aid it is incumbent upon mission planners to ensure a substantial degree of safety to this crew. Historically, most vehicle failures are of the propulsion/controls type. Therefore, an alternate method of ensuring propulsion capability would be to provide two complete propulsion stages and intelligence units mounted in tandem, useable one-at-a-time, and surmounted by a single crew cabin.
5. Provision for manual control of each RCS thruster separately.

6. Provision for the crew capsule and instrument unit (IU) to separate from a failed propulsion module. This would allow the RCS, assumed part of the IU, to provide a much greater delta velocity if needed to return the crew to a safe haven.

Remedial measures:

1. External assistance from a second vehicle to stop tumbling, provide any needed consumables, and propel the disabled tug and crew to a safe haven. If the tumble rate is slow enough the crew could wear PLSSs and leave the tug by jumping out where they will be picked up by a rescue spacecraft waiting close by for them. Should the tumble rate be large enough so that the crew could not exit in this manner then some method will have to be used for slowing the tumble rate or stopping it. The problem is too complex to give specific details here; a separate study is warranted.

Escape/Rescue Requirements for Hazard 1

A rescue vehicle must be provided to rendezvous with a disabled tug in lunar orbit, arrest tumbling motions if present, provide expendables if needed, and propel the disabled tug and crew to a safe haven. If the tumbling cannot be arrested, provision must be made for removing and rescuing the crew via EVA.

Effects of Hazard 2, Disabled Tug Unavailable for Rescue Support

Disabling of any tug in lunar orbit renders that vehicle unavailable for rescue service. Further, if this disabled vehicle requires outside assistance a second rescue vehicle must be committed to that duty. If only two vehicles with rescue capability are normally based in lunar orbit this hazard could occupy both, and leave other orbital and surface systems unprotected.

Corrective Measures for Hazard 2

Preventive measures:

1. Provision of self-help capability for the disabled tug to avoid need for assistance. Possible self-help methods include:
 - a. One or two AMUs aboard the tug which may be worn by one or two astronauts could be used to tow the other astronauts to a safe haven provided it was within the range capability of the AMUs. Optimally the PLSS-wearing crew could leave the tug and orbit until they were within range of a safe haven that could be reached by the use of the AMUs.
 - b. An auxiliary propulsion unit attached to the exterior of the tug and detachable from it could serve the same purpose.
2. Provision of a minimum of three vehicles in the lunar complex with the capability of supporting a rescue mission. One tug is assumed to be on the lunar surface engaged in a sortie-investigation, a second is presumed to be engaged in orbital operations away from the space station, and the third is docked at the station, quiescent, monitored, filled with propellant and ready for any rescue situation.

No remedial measures have been identified for Hazard 2.

Escape/Rescue Requirements for Hazard 2

No additional escape/rescue situation is identified, but a backup rescue vehicle should be made available.

Effects of Hazard 3, Potential Collision

A disabled tug in lunar orbit presents a potential collision hazard to other orbital systems. If the reaction control system, with translation capability, is operative then collision can be avoided. The hazard results only when attitude control is lost.

Corrective Measures for Hazard 3

Preventive measures:

1. Provide two independent attitude control systems, each having the capability to provide translational delta velocity of 50-to-100 ft/sec.

Remedial measures:

1. Rescue of crew and capture of the disabled tug by a rescue vehicle.
2. Disposal of a derelict tug, following crew removal, by deorbiting or by returning it to a lunar station for repair.

Escape/Rescue Requirements for Hazard 3

A rescue mission is required to remove a disabled orbital vehicle from danger of collision with other systems in lunar orbit.

HAZARD STUDY 10
SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. Each manned tug on a solo mission in lunar orbit shall carry expendables adequate to support the crew for a period of seven days beyond the planned mission time.
2. Two independent reaction control systems shall be provided on each manned tug, with each system having the capability to provide translational delta velocity of 50 - 100 ft/sec.
3. A small secondary maneuvering propulsion system oriented in the same direction as the main engines and operating off the main propellant supply, shall be provided to back up the primary propulsion system of any tug in lunar orbit.
4. Where outside assistance cannot be available, such as during initial manning of an orbiting lunar station, the crew compartment of a manned tug in lunar orbit shall be carried on two complete tug propulsion modules and instrument units mounted in tandem.
5. The crew of a manned tug in lunar orbit shall be provided the capability for manual control of each RCS thruster separately.
6. Each crew capsule and instrumentation unit, including RCS, on a tug in lunar orbit must be provided the capability to separate from a failed propulsion module and proceed to a safe haven or await rescue.
7. When lunar surface missions are being performed, a minimum of three vehicles capable of supporting an escape or rescue mission must be provided; one is a standby reserve vehicle in lunar orbit; one is a mission vehicle in lunar orbit; one is a mission/escape vehicle on the lunar surface.
8. A capability for a rescue vehicle to arrest a tumbling manned tug in lunar orbit, provide any needed consumables, and propel the disabled tug and crew to a safe haven must be provided.
9. A capability to dispose of, or salvage, a derelict tug in lunar orbit, following removal of the crew, must be provided.

HAZARD STUDY 11

COLLISION IN LUNAR ORBIT

INTRODUCTION

Collision in lunar orbit could occur between two space vehicles or between a vehicle and space debris. The probability of such an occurrence, resulting in a hazard to lunar crewmen, appears to be quite low if spacecraft trajectories, orbits, and relative velocities are carefully planned and controlled.

Meteoroid collisions are discussed separately in Hazard Study 38.

ASSUMPTIONS

It is assumed that each spacecraft arriving, departing, or operating in lunar orbit has propulsion and attitude control subsystems permitting control of trajectory and velocity and evasive maneuver capability.

THE MAJOR HAZARDS

A collision in lunar orbit could have very serious consequences, ranging from damage to spacecraft subsystems and rupture of pressure shells to total destruction through crushing, explosions, and fire. This study cannot deal adequately with the multitude of situations that could result from a collision, but rather will suggest measures that can be taken to prevent collisions from occurring.

ANALYSIS OF IDENTIFIED HAZARDS

Effects of the Hazard

As discussed above, the effects of a collision can vary so widely that this

aspect cannot be adequately covered in this study. The approach taken is to eliminate the "effects" by avoiding collision.

Corrective Measures to Prevent Collision

Collisions may to a large extent be avoided, or limited to very minor, non-hazardous events by operational planning and procedures, collision risk detection, and avoidance capability. The following preventive measures are proposed. Where numerical limits are suggested, additional study is recommended for verification.

1. No two undocked spacecraft should be based in near-identical or intersecting orbits.
2. No two spacecraft should be permitted to approach each other on a collision course either with main propulsion engines "on" or with a closing velocity greater than about 2 ft/sec.
3. A vehicle intending to dock in orbit shall not be placed on a collision course with the primary propulsion burning.
4. All prime transport vehicles arriving in lunar orbit should rendezvous at an altitude different from that of the target station by 1000 ft or more.
5. To accomplish docking following rendezvous, altitude adjustment should occur first followed by establishment of an intercept trajectory. Only docking thrusters should be used, and closing velocity limited to a maximum of about 2 ft/sec until about 200 ft from contact. From 200 ft to contact velocity should be limited to less than 1 ft/sec.
6. Vehicle or subsystem appendages should be kept clear of docking areas on space vehicles.
7. Spacecraft docking mechanisms should be designed to absorb twice the normal maximum expected docking impact energy without damage.
8. Spacecraft departing a second vehicle should first make an altitude adjustment sufficient to ensure that orbits are non-intersecting before initiating main thrust. This ensures that no common orbital point will exist if departure propulsion or control should fail.

9. The position of space debris in orbit about the Moon should be monitored, and each such debris should be removed at the earliest opportunity should any danger of collision exist. If debris removal is impractical, spacecraft threatened with collision should select a new, safe orbit.

Escape/Rescue Requirements

If collision occurs in lunar orbit, rescue may be required.

HAZARD STUDY 11
SUMMARY OF SAFETY GUIDELINES CANDIDATES

The following guidelines are proposed as candidates to help avoid collisions in orbit about the Moon:

1. No two space vehicles or structures shall be based in near-identical or intersecting orbits.
2. No two space vehicles shall be permitted to approach each other on a collision course either with main propulsion "on" or with a closing velocity greater than about 2 ft/sec.
3. A vehicle intending to dock in orbit shall not be placed on a collision course with the primary propulsion burning.
4. To accomplish docking following rendezvous of two vehicles in orbit, altitude adjustment shall occur first, followed by establishment of an intercept trajectory. Only docking thrusters shall be used for velocity adjustment, and closing velocity shall be limited to a maximum of about 2 ft/sec until about 200 ft from contact. From 200 ft to contact the closing velocity shall be limited to less than 1 ft/sec.
5. Docking areas on space vehicles shall be kept free of vehicle or subsystem appendages such as engines, antennas, and solar cells.
6. Docking mechanisms shall be designed to absorb twice the normal maximum expected docking impact energy without damage.
7. Spacecraft departing from a second vehicle shall first make an altitude adjustment sufficient to ensure that orbits are non-intersecting before initiating main thrust.
8. The positions of all objects in lunar orbit, including space debris, shall be monitored. Debris shall be removed at the earliest opportunity should any significant possibility of collision exist. If debris removal is not practical, the orbit of vehicles threatened with collision shall be appropriately altered.

9. Each manned vehicle in lunar orbit shall be constantly monitoring other traffic, emergencies, or malfunctions that could present a hazard and shall have the ability to maneuver to avoid collision.
10. Orbital tugs shall have the capability to capture and control or dispose of any vehicle or object in lunar orbit. The vehicle may be chemical or nuclear powered, stable or tumbling.

HAZARD STUDY 12
MANNED TUG MANEUVERING ERRORS IN THE VICINITY
OF A NUCLEAR PROPULSION STAGE

INTRODUCTION

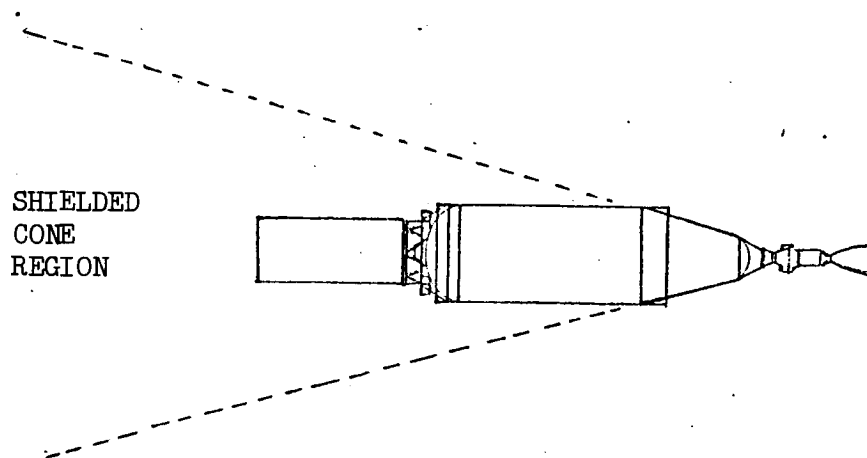
A manned tug, operating in the vicinity of a nuclear propulsion stage, must be constrained in its mode of approach to avoid the hazard of nuclear radiation. This study considers the extent of the operating constraints and the consequence of violating these constraints.

ASSUMPTIONS

1. Transfer of all payload cannisters or crew transport modules from a nuclear powered vehicle to an orbiting lunar station and elsewhere is accomplished by, or controlled from, a manned tug. Where an unmanned tug is used for actual transfer, it will be under control of a manned tug physically located nearby.
2. Primary responsibility for tug maneuvers is vested in the tug commander.
3. The nuclear powered transport vehicle, the orbiting lunar station, and the propellant depot are assumed to be stable passive targets for rendezvous and docking activities of the tug vehicle.
4. Tracking information is initially provided by the orbiting lunar station until target acquisition is accomplished by the tug vehicle. After acquisition the tug provides its own data. The orbiting lunar station continues to monitor the tug and target until out of range.
5. A tug crew for orbital sorties and logistics operations is assumed to vary between two and six men.

The principle hazard generators are those planned or unplanned maneuvers which place the manned tug in close proximity to a nuclear powered vehicle,

but outside of the radiation shielded cone envelope in the forward region of that vehicle. The region protected by the nuclear engine shield and the tankage for a typical nuclear propulsion state is approximately a 30° cone aligned with the vehicle axis, having its apex at the engine reactor core center point. The shield region geometry is illustrated in the following sketch.



TYPICAL NUCLEAR POWERED VEHICLE

The inadvertent placement of the tug crew in the radiation environment of the nuclear stage can arise as the result of one of several sets of circumstances:

1. From human error in trajectory data input which permits the tug to arrive at the nuclear stage in the region of the nuclear engine exposure.
2. From faulty guidance and navigation equipment.
3. From erroneous range data resulting from malfunctioning range radar.
4. From failure to verify nuclear stage orientation prior to approach resulting in closure on nuclear engine in a darkside passage.
5. From a closure velocity error which requires a translation maneuver to

miss collision with nuclear stage payload and permits the tug to penetrate an unshielded region.

6. From propulsion systems inoperative on-board the tug, leaving the tug with excess velocity relative to the nuclear stage and causing passage through the engine radiation field.
7. From failure of the tug power system during tug/nuclear stage rendezvous sequence causing the tug to drift by the nuclear stage at low relative velocity.

THE MAJOR HAZARD

The major hazard generated by inadvertent entrance into the unshielded radiation region around the nuclear stage is the potential exposure of man to excessive amounts of nuclear radiation.

ANALYSIS OF THE HAZARD

The hazard identified is exposure of men in a tug crew compartment to nuclear radiation while operating in the vicinity of a nuclear propulsion stage.

Effects of the Hazard

The penetration of a tug vehicle into the radiation environment surrounding the nuclear powered vehicle will result in crew exposure of some magnitude. The effects of such an exposure will range from a small increase in the crew radiation dose burden, to major significant dose increases which can expend the crew allowable dose limit, to a crew dose burden reaching into the physiological damage region.

The crew dose in all seven of the cited situations is a function of the exposure time and the spatial position radiation dose rate. Since the crew will be moving through a region of changing dose rate as the radiation source is approached and passed, the integrated dose to the crew is normally computed

for small time steps to accommodate the changing exposure function. For purposes of this study, however, it is sufficient to make a conservative approximation of the expected exposure values and address the problem in terms of these approximate values.

The representative situation to be considered is given as follows:

Assume that a nuclear stage payload is to be removed one day after arrival at the Moon. Further, assume that the tug vehicle in performing the necessary orbit transfer and phasing maneuvers to achieve rendezvous with the nuclear stage suffers a loss of power in the final orbit circularization maneuver such that the tug will fly by the nuclear stage. For the analysis it is assumed that the fly-by velocity is on the order of 1 meter per second relative to the nuclear stage and the tug will pass the nuclear engine at a distance of 30 meters. Taking the stage and payload length to the nuclear engine (reactor-core) center to be close to 53 meters, it is then possible to compute the tug crew exposure resulting from the postulated mishap.

Ref. 1, Supplemental Data Report No. 1 presented in Appendix E, should be consulted and considered a part of this study. Several Figures from Ref. 1 are pertinent to the following discussion. The ambient fission-product dose rate at a position 30 meters from the side of the NERVA nuclear engine is given in Figure 4 of Ref. 1. The data are presented for a view angle of 90° as a function of time after engine shutdown. Dose - distance data over a wider range of distance is given in Figure 5 of Ref. 1.

The variation in gamma radiation dose rate for the entire engine view-angle range seen by the tug in its fly-by is obtained from Figure 6 of Ref. 4. The appropriate "view-factor" is applied to dose rate data from Figures 4 and 5 of Ref. 1 to obtain a corrected dose rate for any point in the tug path.

Figure 1 presents the corrected dose rate profile for the tug fly-by of the nuclear engine. Included is a sketch of the fly-by situation showing the

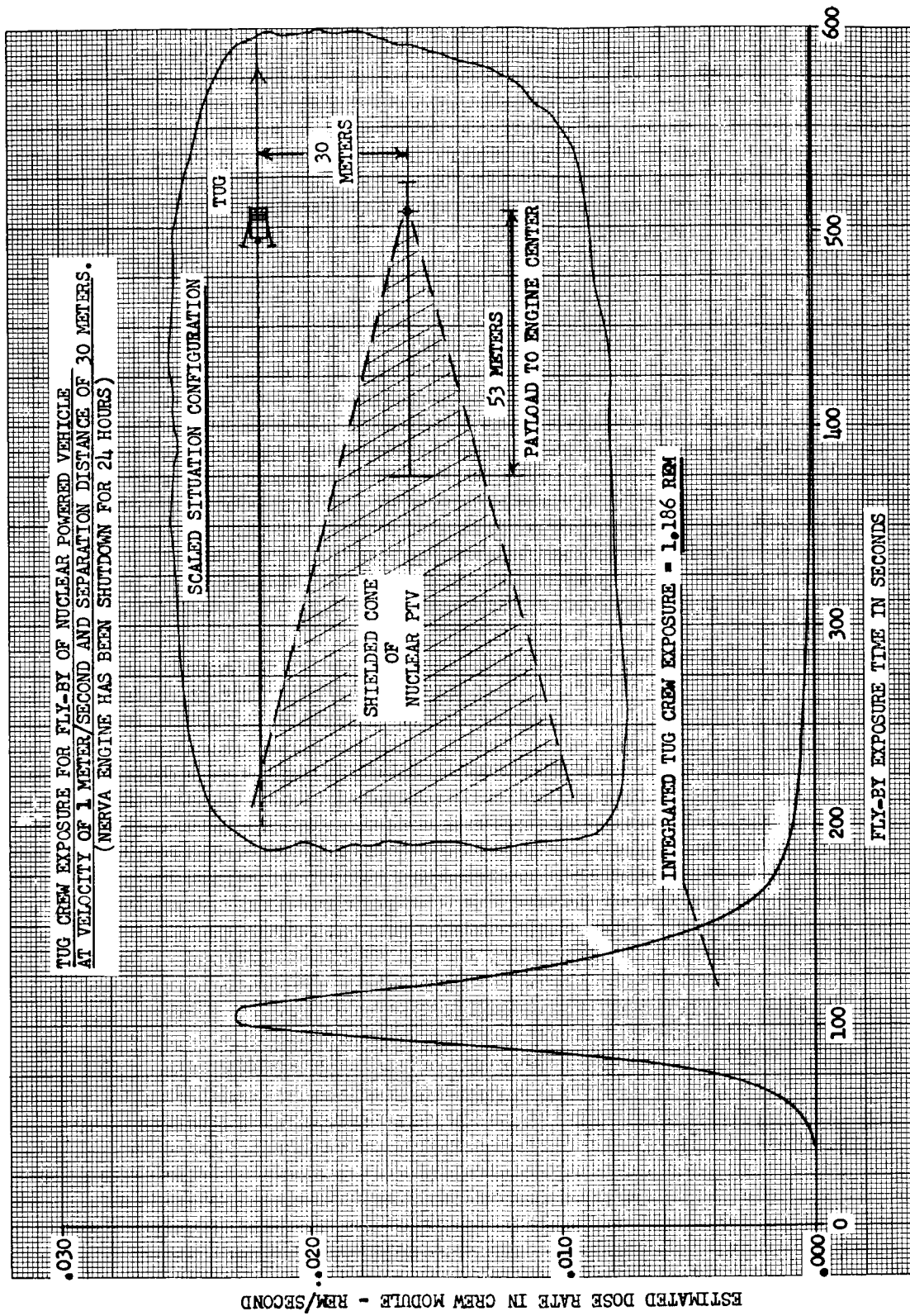


Fig. 1 Tug Crew Exposure for Fly-by of Nuclear Powered Vehicle

parameters considered. The integrated tug crew exposure values as a function of fly-by velocity are given below for a tug/nuclear engine approach distance of 30 meters and an engine shutdown time of one day.

<u>Velocity</u> (Meters/Sec)	<u>Crew Dose</u> (REM)
3.04	0.4
1.0	1.2
0.304	3.9
0.0304	39.0

In all cases the exposure integration was performed over the time required for the tug to traverse 600 meters relative to the nuclear stage. The data clearly illustrate that the tug stay-time in close proximity to the nuclear engine must be controlled to minimize crew dose accumulation. A disabled tug in close proximity to a nuclear stage must be removed as expeditiously as possible.

Corrective Measures

Preventive Measures:

1. Tug vehicles shall be equipped with on-board radiation sensors and instrumentation which alarm and call attention to the fact that the vehicle is penetrating a region of increasing radiation level.
2. Tug vehicles shall be so designed that total failure of all on-board propulsion capability or attitude control cannot result from failure of a single system or subsystem.
3. Normal tug operating procedures shall require phasing termination, in the vehicle radiation shield cone, at a distance of at least 350 meters from a nuclear powered vehicle.
4. Do not plan activity around the NPTV until it is stabilized and has been shut down for one or more days.

Remedial Measures:

None identified.

Escape/Rescue Requirements

Should the tug become totally propulsion disabled, as in the above situation, external assistance will be required to remove it from the vicinity of potential radiation exposure.

SOURCE DATA REFERENCES

1. "A Study to Evaluate Radiation Exposure to the Orbiting Lunar Station and Lunar Surface, Related to the Reusable Nuclear Shuttle Operations" Supplemental Data Report No. 1, Appendix E, of this report.
2. Nuclear Stage PDD, MSC, April 13, 1970.
3. Nuclear Shuttle System Definition Study, Phase III, Monthly Progress Report, LMSC-A980259, November 15, 1970.

HAZARD STUDY 12
SUMMARY OF SAFETY GUIDELINE CANDIDATES

The safety guideline candidates derivable from the analysis are as follows:

1. No single function failure of any system or subsystem on board a tug shall result in loss of capability to control attitude and velocity of that tug.
2. Normal tug operating procedures shall require phasing termination, in the vehicle radiation shield cone, at a distance of at least 1,150 ft from a nuclear powered prime transport vehicle.
3. Tug operations in the vicinity of a nuclear prime transport vehicle shall be constrained by adequate procedures such as rigid control of approach path - velocity - distance parameters, to prevent inadvertent intrusion into the nuclear vehicle radiation zone during normal transfer and phasing maneuvers.
4. No activity shall be planned around a nuclear stage until it is stabilized and the nuclear engine has been shut down for at least 24 hours.
5. Tug vehicles shall be equipped with on-board radiation sensors and instrumentation with provision for auto-alarm whenever the tug vehicle is penetrating a region of increasing radiation level.

HAZARD STUDY 13

PROPELLANT DEPOT IN LUNAR ORBIT

INTRODUCTION

This study area includes discussion of hazards associated with depot basing schemes and propellant transfer methodology for a propellant depot in lunar orbit. The consideration of a propellant depot on the lunar surface, as well as discussion of the necessity for a propellant depot in the lunar complex, is dealt with in Section 3.

The establishment and use of a propellant depot (or farm) in lunar orbit in some form is assumed for the conduct of manned operations including rescue on the Moon and in lunar orbit (see Section 3.) Such a propellant farm can take many forms and be located either at (i.e., attached to) an orbiting lunar station (OLS) or sited in orbit at some convenient distance from the OLS. If separate from the OLS, the farm can be completely dormant and serve only to receive and transfer propellants from or to a spacecraft. Alternately, it may be desirable to maneuver the farm to be near or docked at the OLS for propellant transfer operations. If the latter, the farm may be maneuvered to the OLS unmanned or a pilot may be put aboard for this purpose. A special case of the maneuverable propellant farm is that of tug alone loaded with propellant in lunar orbit.

There is a distinct lack of knowledge in a number of areas which inhibits a complete discussion of this topic; these include:

1. The lunar environment is not defined well enough in that the frequency and sizes of meteoroids as a function of time (per unit area, assuming isotropic distribution) is not known. The statistics supplied by the Lunar Orbiters are insufficient.
2. The entire area of propellant depot design has no substantial definition.
3. The power system for operating the depot propellant transfer functions has not been determined.

4. The degree of automation in loading and unloading procedures for propellant at the depot is unknown.

In order to make well founded decisions on the propellant depot basing and transfer techniques, detailed studies will have to be conducted in each of the areas noted. It is recommended that such studies be instituted.

ASSUMPTIONS

- a. The propellant depot is in the same orbit plane with the OLS and has the same perigee and apogee.
- b. The depot is never further than 200 miles away, and preferably closer for spacecraft delivery of propellant to the depot or for transfer of propellant to a spacecraft.
- c. The depot has attitude control at all times in lunar orbit.
- d. The depot has its own power supply for pumps for propellant transfer to and from depot tanks. If the depot does not have its own power, a considerable demand will then be made on the power system of the vehicle conducting the propellant transfer.
- e. Whole tanks of propellant may be transferred to the using spacecraft; i.e., tank plus propellant; alternately propellant may be pumped aboard.
- f. The depot has a framework into which the tanks are set. The frame carries a series of flashing lights and beacons. The frequency for these beacons are made known to all space-faring nations.
- g. All of the depot framework is designed with tethering places and hand holds so that, if necessary, an EVA astronaut can reach a working position at any tank connecting link or at any propellant transfer connection.
- h. A separated depot in less than 200 miles from the lunar station, preferably much closer. It is recommended that a study be conducted to determine the optimum method(s) for station-keeping for the depot.
- i. In the case of a depot attached to a space station, it is in a position facing the lunar surface and rigidly attached. In the event of such

- a need, that portion of the depot holding the tanks should be separable from the space station.
- j. Unattached, the depot may be rotated to aid in the propellant transfer process.
- k. An entire station with depot attached will not rotate as a unit to initiate acceleration for propellant transfer.

THE MAJOR HAZARDS

The major hazards identified are:

1. Collision between depot and spacecraft.
2. Explosion of a loaded or partially loaded tank due to a meteoroid strike.
3. EVA astronaut on umbilical gets entangled in depot.
4. Tank mishandled when being transferred to depot, 'escapes' to form hazard in depot - OLS orbit.

ANALYSIS OF IDENTIFIED HAZARDS

Hazard 1, Collision between the Depot and a Spacecraft, is dealt with in Hazard Study 11 and is not, therefore, repeated here.

Effects of Hazard 2, Meteoroid strike on propellant tank

An explosion of a propellant tank will result if it is struck by a meteoroid large enough to penetrate the tank and impart sufficient energy to the propellant. If such an event occurs at the time that a propellant transfer operation is underway, the spacecraft involved could be severely damaged or destroyed. The depot could sustain damage ranging from destruction of the struck tank to severe degradation of all operations with the depot.

As a result of such an explosion, the safety of other spacecraft crews in lunar orbit will be endangered by debris that has orbits intersecting those of such spacecraft.

Some debris will almost certainly be deorbited so that the crews of vehicles and shelters on the surface could be struck.

A severe explosion could be generated by a meteoroid strike with the depot and could cause damage to the attached OLS to the extent of piercing the main cabin and causing a loss of atmosphere which then endangers the entire crew. Cabin atmosphere may be lost over periods ranging from minutes to hours. The latter period implies a puncture repairable, perhaps, with some of the crew in space suits and others in safe isolatable areas; this level of problem will not be considered further. The loss of atmosphere measured in minutes is our present concern. The effects of such an event include:

1. Loss of atmosphere and subsequent loss of crew in ruptured cabin area unless crew can get to safe compartment soon enough.
2. Loss of communications through debris collision.
3. Severe damage to tugs docked to OLS leading to degradation of rescue capability.

Corrective Measures for Hazard 2

Preventive Measures:

1. A propellant depot attached to an OLS should be in the OLS 'shadow'. This lessens the area for a meteoroid strike on the depot. The depot would be attached to the OLS on the side facing the lunar surface.
2. A grid should be considered for placement between an OLS and a propellant depot so that large debris from any propellant tank explosion will be deflected or trapped. The grid should 'shadow' all of the OLS plus tugs parked at end ports of the OLS.
3. Design meteoroid shields into all tankage with shield protection capability to be maximum obtainable within engineering feasibility and cost factors as deemed appropriate. Established meteoroid design criteria should be used.
4. In addition to protection offered in 3 above, design a detached depot to maintain gravity-gradient-supported attitude and add a meteoroid shield to depot frame in horizontal plane on face furthest from lunar surface.

Remedial Measures:

1. Large chunks of debris with intersecting orbits should be captured by tug and deorbited to the lunar surface.
2. Prevent collision by capturing large chunks of debris in intersecting orbits. Eventually capture all debris on intersecting orbits.

Escape/Rescue Requirements for Hazard 2

1. Orbiting lunar stations should be compartmented so that multiple areas exist for the crew to go to in the event of one pierced cabin.
2. Rescue will probably be required in the event of a propellant depot explosion adjacent to an OLS.
3. If spacecraft at a detached propellant depot are damaged, rescue will be required.

Effects of Hazard 2, Astronaut Entangled in Depot

An astronaut in EVA mode connected to his spacecraft by long umbilical and performing operations at propellant depot gets entangled in the propellant depot and therefore is unable to return to his spacecraft. The astronaut could run out of consumables and be lost if he is not rescued. In efforts to free himself, the astronaut may detach his umbilical or rip his spacesuit and therefore lose oxygen and be asphyxiated.

Corrective Measures for Hazard 3

Preventive Measures:

1. Wear PLSS for all propellant depot EVA operations.
2. Use cherry picker-EVA mode described in Hazard Study 7.

Remedial Measures:

1. First aid - resuscitation methods in a safe enclosure should be applied by fellow astronauts engaged in rescue if the rescuers are late in arriving. The use of the buddy system will ensure early aid and may be a preventive method as well.

Escape/Rescue Requirements for Hazard 3

1. If umbilical is to be worn, then also wear a 30 minute PLSS. Cut entangled umbilical free after activating PLSS and return to spacecraft immediately.
2. Send second EVA astronaut out to disentangle first astronaut.

Effects of Hazard 4, Mishandled Tank Escapes

One of the suggested methods for attaching loaded tanks to the propellant depot encompasses the use of manipulators and automatic connection devices. Another requires EVA astronauts to connect the tanks. Independent of the method used for such installation a misstep can lead to the tank floating free in orbit and consequently presenting a hazard to the depot and other spacecraft in lunar orbit. The hazard may occur, of course, in detaching a tank from the depot. The effects that may occur due to a tank floating free in lunar orbit include:

1. Collision with other spacecraft (including the OLS and the propellant depot). A derelict in lunar orbit.
2. Collision with the EVA astronaut handling the procedures for attaching the tank to the depot with resulting injuries to the astronaut.
3. Loss of all the propellant in the tank if it is a full one. It may be a last available tank and needed for rescue.

Corrective Measures for Hazard 4

Preventive Measures:

In delivering or removing a tank to or from a depot, add a design element to permit tethering to the depot or tug before release from the delivering spacecraft or release from the depot.

Remedial Measures:

In designing tanks add handles or rails for grasping by the tug in retrieval procedure, should tank actually float away from the depot.

Escape/Rescue Requirements for Hazard 4

None necessary.

Additional information:

Overfilling or underfilling propellant tanks were examined from the hazard/safety viewpoint. An overfilled tank vents to space, and at worst some propellant is lost from one of the tanks involved. Only one propellant is transferred at a time. Moreover, LOX and LH₂ are not hypergolic. Any escaped propellant will quickly dissipate in the space environment. If it is spacecraft tanks that are being filled, there would have to be a double failure to overfill; failure of measuring devices on both the depot and the receiving craft. Additionally, the two measuring devices would have to register equal amounts dispensed and received in order for the failure to be overlooked by the monitoring crew members.

The procedures leading to underfilling in either direction - to or from the depot - would also require two failures with both dispenser and receiver measuring devices not only failing but showing identical and incorrect amounts of propellant transferred.

Such double failures together with identical errors on both (failed) measuring devices are thought to be completely unrealistic.

HAZARD STUDY 13
SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. Always tether propellant tanks the depot during delivery, or to tug during removal, to prevent these tanks from becoming a collision hazard in orbit.
2. EVA astronaut(s) should not use long umbilicals in and about a propellant depot in order to avoid entanglement of the umbilical with any part of the depot structure or mechanisms.
3. Propellant depot tankage should be designed with maximum meteoroid shield protection commensurate with engineering feasibility and cost and penetration depth probability.
4. A propellant depot attached to an orbiting lunar station should be placed between the OLS and the lunar surface in order to lessen the area of depot exposed to meteoroid strikes.
5. To prevent the collision of large pieces of debris with an orbiting lunar station following a propellant tank explosion, design and emplace a grid between the propellant depot and the OLS. The grid should shadow the OLS-docked tugs at the end port.
6. When a propellant depot is attached to an orbiting lunar station, keep one tug docked at a transverse port on the side of the OLS away from the depot to prevent debris from striking the tug in the event of explosion of a propellant tank.

HAZARD STUDY 14
INJURY OR DAMAGE DURING CARGO HANDLING IN ORBIT

INTRODUCTION

The delivery of cargo to the lunar space station or to a tug in lunar orbit presupposes concern with a number of related problems. These include:

1. Guidance and control good enough to keep rates low to avoid collision in docking.
2. The imposition of docking hatch size on cargo packages (modules) to be delivered.
3. Actual delivery mode can include:
 - a.Entire delivery vehicle docks to receiver
 - b.Cargo bay is separated from delivery vehicle and then docks to receiving vehicle. If the latter, the cargo module needs separate propulsion, guidance, and control.
4. Whether or not the cargo bay arrives at lunar orbit internally pressurized.

Some items such as experiments attached to the space station externally, propellant, and tanked and pressurized consumables generally are not brought aboard the lunar space station or other spacecraft in lunar orbit. However, oxygen for emergency use and some gases associated with experiments, both in pressurized tanks, are very likely to be brought on board the lunar spacecraft. In particular, oxygen tanks to supply the PLSS's as well as the PLSS tanks themselves are highly pressurized. No liquids are likely to be pumped aboard the station due to the deterioration of plumbing connection seals when corrosive liquids are handled and the subsequent maintenance problems encompassed. Non-corrosive, passive liquids (e.g., water) are more easily handled by carrying tanks aboard. Because this study is limited to the cargo handling itself, a number of assumptions are made -- not intended to represent a final system, but only one of many alternatives -- to establish a scenario for cargo handling in lunar orbit.

ASSUMPTIONS

1. If cargo is delivered via an unmanned, nuclear prime transport vehicle (PTV) then the PTV will stand off from the station about five miles and a manned tug will move the cargo module from the PTV to the lunar space station. It will be possible for a crewman to enter the cargo module to aid in the docking procedure at the station. Ref. 1, 2.
2. In order not to impose additional burdens on the lunar space station all cargo modules arrive pressurized at the level of the lunar station.
3. There are hatches and docking hardware at both ends of the cargo modules. Ref. 1, 2.
4. Cargo module docking ports are compatible with the Earth space station as well as the lunar space station; this means port diameters permitting passage of a 5-foot diameter cylinder. Ref. 1, 2, 3.
5. Crew members handling docking procedures will have visual access to the cargo module during docking (this is based on decisions used in the Earth space station studies by North American Rockwell, Ref. 3).
6. When cargo modules and crew modules arrive together on a PTV they can be removed by a tug and docked as a unit to the station. Then the crew can pass through the cargo module into the space station. This passage is preferred so as to avoid carrying or moving cargo through the crew module and thus exposing crew module instrumentation to the possibility of "collision" with such cargo.
7. Cargo handling is accomplished in a shirtsleeve environment. Ref. 1, 2, 3.

THE MAJOR HAZARD

The major hazard identified is a cargo container (package) which "escapes" while being manually moved from module to station.

ANALYSIS OF IDENTIFIED HAZARDS

Effects of "Escaped" Cargo Package Hazard

An escaped or improperly handled cargo package being moved within a zero g space vehicle may strike and injure a crew member or damage and disable a vital subsystem.

Corrective Measures

Preventive Measures:

1. Except for the size of package that can be comfortably tucked under one's arm all cargo containers and packages are best constrained during transfer from the cargo module to the space station or to a tug. The small package is not likely to be encountered during such cargo transfer. (It should be observed, however, that if a cargo module is docked at the station and is used in the pantry concept many containers are opened in the cargo module for removal of relatively small packages - small in size and mass - for transfer to the station or tug).
2. Assuming that a package is less than 500 lb and has dimensions such that:
 - a. An astronaut can "peer" around a package to see his intended translation path, and
 - b. will easily pass through the docking hatch, then the package may be handled by one man.
3. A package less than 1000 lb (but over 500 lb) and less than 20" x 30" x 40" in dimensions should be handled by two men.

4. Packages over 1000 lb (Earth weight) and/or over 20" x 30" x 40" in size (for a box-like shape) are best moved using restraining systems such as the pallet and rails method described in Ref. 1 and 2. A detailed human factors/engineering analysis in Ref. 1 is the source of the numbers quoted here.
5. Limit packages to sizes that comfortably pass through the docking port - observing that handling hardware must also be emplaced in the open port area.
6. Select techniques of moving cargo packages from their stored positions in the cargo module to the module transfer-to-station system that ensure package restraint at all times. Again, such a system is discussed in Ref. 1.
7. For any movement of cargo packages, grasping points are desired. A generous handhold and adequate clearance to reach the grasping point should be ensured.

No remedial measures have been identified.

Escape/Rescue Requirements

None required.

DATA SOURCES REFERENCES

1. Unnumbered LMSC Report, "Space Station Program Interim Logistics Vehicle Study Report," S. B. Kramer, et al, 9 June 1969; Section on Cargo Handling - Part II.
2. LMSC-A955317, "Integral Launch and Reentry Vehicle (ILRV)," 31 July 1969; Section 12.1.3 on Cargo Handling.
3. Space Station Program, Phase B, Definition, Vol. V, MSC-00720, NASA NAS 9-9953; North American-Rockwell, July 1970, and Space Base Definition, Vol. II, MSC-00712 (part of the Space Station Program, Phase B, Definition) North American-Rockwell, July 1970.

HAZARD STUDY 14
SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. It is strongly recommended that cargo packages whose dimensions exceed 20" x 30" x 40" or whose Earth weight exceeds 1000 pounds be moved from the cargo module to the lunar space station, or to a tug, using a restraint/transport method such as guide rails.
2. A package whose Earth weight is greater than 500 pounds but less than 1000 pounds and whose dimensions do not exceed 20" x 30" x 40" should be handled by two crew members when in a zero-g, shirtsleeve environment.
3. In order for a package to be handled by one man in a zero-g shirtsleeve environment, it should: (a) have dimensions permitting comfortable handling and vision, and (b) be less than 1,500 pounds Earth weight.
4. Cargo containers/packages should be designed to provide generous grasping points or handholds.
5. In order to minimize hazards associated with cargo handling in orbit, the pantry technique is recommended for receiving cargo. In such a method the cargo module is docked to a logistics port at the station, cargo is removed on an as-needed basis, the cargo containers are opened in the module and the contents removed in separate pieces as needed. This technique requires entry to the module on a daily (or more frequent) basis but the handling is reduced, in large part, to removal of small packages.

HAZARD STUDY 15

INCORRECT DESCENT OR ASCENT TRAJECTORY OF A MANNED LUNAR LANDER TUG

INTRODUCTION

During the course of advanced lunar operations there will be many trips to and from lunar orbit and the lunar surface. As time progresses, such expeditions to the surface are likely to encompass exploration of any location on the lunar surface that proves of interest, including the far side.

On any trip, the possibility exists of a malfunction of navigation equipment or data input leading to an unplanned and undesired trajectory. The navigation type of malfunction is the sole concern of this Hazard Study with propulsion and control failures discussed in Hazard Study 16.

ASSUMPTIONS

1. Two types of trajectories could occur from a navigation malfunction during descent to, or ascent from, the lunar surface:
 - a. An undesired lunar surface impact trajectory
 - b. An unintended orbit about the Moon
2. No propulsion, control, or communication malfunction has occurred.

THE MAJOR HAZARDS

The major hazards are identified as:

1. A navigation failure or input error has placed a tug on an unplanned impact trajectory with the lunar surface. This may or may not be evident to the tug crew, but if uncorrected will lead to an unplanned landing, to landing at the wrong site, or to a crash. Time available for corrective action may vary from seconds to approximately one hour.
2. A navigation failure or input error has placed a tug in an unplanned, non-impact orbit trajectory about the Moon. This may or may not be evident to the tug crew, but if uncorrected may lead to isolation. Time available for corrective action is on the order of several days.

ANALYSIS OF IDENTIFIED HAZARDS

Effects of Hazard 1, Impact Trajectory from Navigation Error

An unplanned impact trajectory, if not detected and corrected in time, will lead to landing at the wrong site or to a crash. Vehicle damage, crew isolation, and crew injury or death may result.

Corrective Measures for Hazard 1

Preventive measures:

1. The tug guidance subsystem should incorporate backup features and redundancy to provide a high degree of reliability.
2. The tug crewmen must be provided with manual navigation capability and trained in manually controlling the tug trajectory at all points from orbit to landing and return to orbit. The option to assume manual control must be immediately available at all times.

Remedial measures:

1. Since the tug crewmen may be unable to detect a navigation error within an acceptable time, the tug trajectory on descent and ascent should be tracked and status confirmed.
2. Upon detection of a navigation malfunction or error, standard procedure should call for assumption of manual control by the tug crew and redirection of the vehicle to a safe orbit. If a landing was intended, that landing should be abandoned until the navigation system is returned to proper operating condition.

Escape/Rescue Requirements for Hazard 1

If corrective action is not taken, the tug will land or impact at the wrong site, with the possibility of tug structural damage and crew injury or death resulting. A rescue capability would be required to cover this range of possibilities. If outside tracking was not used, and landed crewmen are unable to communicate their condition and position, the tug will be extremely difficult to locate. A crash locator beacon should be mandatory tug equipment.

Effects of Hazard 2, Undesired Lunar Orbit

An unplanned non-impact trajectory will lead to a safe but undesired orbit about the Moon. The tug crew will be isolated until trajectory corrections can be accomplished. Since all systems other than navigation are assumed to be functioning, and the tug will normally carry life support adequate for several days' duration, the crew has adequate time for corrective action.

Corrective Measures for Hazard 2

Preventive measures for Hazard 2 are identical to those for Hazard 1.

Remedial Measures:

With the assistance of Earth tracking, determine the trajectory parameters and the corrections required to return to the orbiting lunar station. Use manual control, or automatic navigation equipment if repair has been accomplished, to return to the lunar station.

Escape/Rescue Requirements for Hazard 2

A crew is in a safe but undesired orbit about the Moon, with navigation failed. Escape is not required. Rescue assistance in the form of navigation information may be required in order to permit a manually controlled return to a lunar station in orbit. If manual navigation capability is not provided, a repair/rescue mission will be required.

HAZARD STUDY 15
SUMMARY OF SAFETY GUIDELINES

1. The crewmen of a lunar lander tug must be provided with manual navigation capability and must be trained in manually controlling the tug trajectory at all points from orbit to landing and return to orbit. The option to assume manual control must be immediately available at all times.
2. All lunar lander tug ascent and descent trajectories shall be tracked and status confirmed.
3. Upon detection or notification of a navigation malfunction or trajectory error, standard procedure shall call for assumption of manual control by the tug crew and redirection of the vehicle to a safe orbit.

HAZARD STUDY 16

LOSS OF PROPULSION OR CONTROL OF MANNED TUG DURING LANDING OR ASCENT TO ORBIT

INTRODUCTION

During the procedure of ascent from or descent to the lunar surface, the interval with main propulsion active is critical. If lunar lander tug propulsion fails or attitude control is lost during ascent or descent using some of the proposed concepts for the tug, the crew will be lost.

ASSUMPTIONS

1. Main propulsion or attitude control has failed during ascent from or descent to the lunar surface.
2. The crew members are all wearing space suits and are on the LSS suit loop during ascent or descent. (This is an aid if a survivable mishap occurs wherein the cabin pressure shell is ruptured.)
3. Lunar surface landing commences from a lunar orbit with a perilune of 50,000 feet above the mean lunar surface.
4. Descent insertion commences at an appropriate time before reaching the 50,000 feet altitude point.
5. Main engine on at the 50,000 ft point commits the tug to a landing.

THE MAJOR HAZARDS

The major hazards identified are:

1. If the tug loses attitude control or does not obtain sufficient ΔV to go into a lunar orbit during ascent it will be on an impact trajectory. If no further steps are taken, the tug will be destroyed and the crew lost in a lunar surface impact.

Additionally, in the event of main propulsion failure or loss of attitude control after a landing procedure is initiated at 50,000 ft the tug will impact the lunar surface and the crew will be lost if no further action is initiated.

ANALYSIS OF IDENTIFIED HAZARDS

Effects of Hazard 1, Loss of Propulsion or Control

If a failure of the tug's main propulsion system occurs during ascent to or descent from lunar orbit such that the acquired tug velocity is less than that necessary for orbiting or insufficient for landing, then the tug will impact the lunar surface. Unless some measure is taken to avoid such an impact the crew will be lost. Should attitude control fail during ascent or descent the results will be the same, the crew will be lost if the malfunction cannot be corrected immediately.

Corrective Measures for Hazard 1

Preventive Measures:

1. In order to circumvent the dangers inherent in a main propulsion system failure, it is suggested that main propulsion consisting of four engines be operated as redundant, throttleable pairs; with each pair capable of performing the ascent or descent function. In this manner a failure in any one engine leads to cut-off of its mate whereupon the thrust of the second pair is increased to continue the ascent or descent.
2. Since the main propulsion engines for the tug can be gimbaled, it is suggested that the attitude control engines and main engine gimbal control be designed as separable functions. This will permit the main propulsion engine to supply control for the tug without the use of the primary attitude control engines should the latter fail. The tug control loops should be designed to use either control mode separately, or to use both sets of engines acting in concert for control.

3. Although the requirement for greatly increased funding is recognized, together with the programmatic implications, an alternate tug design is suggested for consideration as a measure to countermand propulsion failure. The tug could be designed as a two stage spacecraft in the manner of the Apollo Lunar Module, a major difference being that the ascent (upper) stage is only used if the lower stage propulsion (or other critical subsystem) fails during ascent (or descent).
4. Redundancy in all critical main propulsion system parts is suggested so that there are at least two propulsion loops per stage to run the tug engines.

Remedial measures:

1. For use in events where propulsion failure occurs at very low altitude (tens of feet above the surface) an emergency communications device, designed to survive severe impact, should be included in the assemblage of instrumentation for use when some of the crew survive the impact or to locate the downed tug.

Escape/Rescue Requirements

1. If there has been a propulsion or control failure at a very low altitude - tens of feet above the surface - an urgent rescue will be necessary.
2. Other failures considered here lead to loss of the crew - no requirements for rescue exist.

DATA SOURCE REFERENCES

1. Apollo 12 Mission Report, NASA/MS, MSC-01855, March 1970.

HAZARD STUDY 16
SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. The critical nature of lunar lander tug descent and ascent maneuvers demands special attention to items such as redundancy, backup, manual override, propellant reserves, control authority, and anytime-abort where feasible, in all critical functions and subsystems associated with control of velocity and attitude.
2. The main propulsion engines for the tugs in the lunar complex should be designed as redundant, diametrically located pairs; throttleable, with each pair capable of performing the ascent from and descent to the lunar surface.
3. The pilot of a lunar lander tug must be provided the capability to assume manual attitude control at any time.
4. The attitude controls on the tug for the lunar complex should be separable so that either main propulsion (i.e., gimbaling engines) or the RCS, or both could be used for the attitude control function.
5. Include as part of standard equipment aboard all lunar complex tugs a lunar-impact-survivable communications beacon that would activate on impact at some selected acceleration level. In the event of tug impact its location could then be determined.
6. All crewmen shall wear space suits and operate on the LSS suit loop during ascent and descent between lunar orbit and lunar surface.

HAZARD STUDY 17

LOSS OF TUG PROPULSION ON THE LUNAR SURFACE

INTRODUCTION AND DISCUSSION

A failure of an ascent propulsion system on the lunar surface will result in the temporary isolation of the crew. They will be in danger only if they do not have sufficient life support provisions.

The crew compartment must be provisioned to support the crew for a period of time following a planned return to orbit until a rescue mission can be accomplished. Depending on the rescue concept, the emergency stay time requirement is estimated to be 7 to 14 days. This would allow a rescue from orbit at a time of minimum energy requirement for the descent and ascent.

ESCAPE/RESCUE REQUIREMENTS

Rescue is required for a solo crew isolated in the crew compartment of a failed tug on the lunar surface. A wait time of 7 to 14 days can be provided the crew while the rescue is accomplished.

SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. A capability must be provided to rescue a crew stranded on the lunar surface because of ascent propulsion module failure.
2. The crew compartment of a solo vehicle on the lunar surface must be provisioned to support the crew for a period of time following a planned return to orbit until a rescue mission can be accomplished. This time is estimated to be 7 to 14 days.

HAZARD STUDY 18

LOSS OF TUG CREW COMPARTMENT HABITABILITY ON THE LUNAR SURFACE

INTRODUCTION

The hazards considered are those resulting from a failure of a critical subsystem in the crew compartment of a solo lunar lander tug on the lunar surface, or from failure of the pressure shell containing the crew.

ASSUMPTIONS

1. It is assumed that the lunar lander tug includes a pressurized crew compartment for several men in a shirtsleeve environment, and an attached airlock nominally used for egress/ingress.
2. Loss of habitability can occur at any time during the surface mission, and the crew situation at the time of the emergency could typically be:
 - a. All crewmen in shirtsleeves inside the cabin.
 - b. Some crewmen in shirtsleeves in the cabin and some on EVA sortie up to several miles distant on a non-cabin roving vehicle.
 - c. Some crewmen in shirtsleeves in the cabin and some are walking EVA close to the tug.
3. The tug crew compartment is provided with contaminant detection and removal equipment.
4. All critical life support system components are highly reliable and have redundant parts.

THE MAJOR HAZARDS

The major hazards identified are:

1. Insufficient time to don space suits following sudden loss of cabin atmosphere. It is assumed this could occur only following fire or a meteoroid strike, collision, or explosion that ruptured the cabin pressure shell.

2. Inadequate power and life support supply to allow time for subsystem repair, return to a safe haven in lunar orbit, or rescue from orbit.
3. Illness or incapacitation or deprivation of oxygen following contamination of cabin atmosphere.
4. Injury following explosion or fire with an internal system such as a high-pressure gas storage vessel, pyrotechnic, or experimental device.
5. Isolation of crew members on EVA traverse if the tug must return quickly to a safe haven in lunar orbit to save crew members at the tug.
6. Inability for crewmen to operate the tug and return to orbit in pressure suits following loss of cabin atmosphere.

ANALYSIS OF THE IDENTIFIED HAZARDS

Effects of Hazard 1, Insufficient Time to Don Space Suits

Insufficient time to don space suits following sudden loss of cabin pressure will result in loss of the crew unless an emergency compartment or emergency pressure garment is readily available.

Corrective Measures for Hazard 1

Preventive measures:

1. Provide two separate pressure compartments in each tug crew compartment, with quick access from one to the other and with pressure suits (or emergency pressure garments) and PLSS's stored in each. The second compartment could be an airlock, with generous dimensions and emergency life support.
2. Provide emergency pressure garments which can be donned more quickly than pressure suits. Atmosphere supply for the garments should be two-gas, if the cabin is two-gas.
3. Keep crewmen in pressure suits at all times, assuming a backup pressurized compartment or emergency pressure garments are not readily available.

No remedial measures are identified for Hazard 1.

No escape/rescue requirements are identified for Hazard 1.

Effects of Hazard 2, Inadequate Power and Life Support Supply

Insufficient emergency power and life support supply to allow subsystem repair, return to station in orbit, or rescue from orbit will result in loss of the crew following failure of a vital tug subsystem.

Corrective Measures for Hazard 2

Preventive measures:

1. Plan each mission sequence such that emergency supplies are always available to allow time for return to safe haven in orbit or rescue from orbit, whichever is greater. Preliminary analysis indicates this time is on the order of 48 hours in the worst case.
2. Use two tugs for each surface mission such that a backup system is always available.
3. Provide capability for operation and return of the tug to orbit by crewmen in pressure suits.

Remedial measures:

1. Provide a "care" package from lunar orbit, if this can be accomplished more quickly than rescue or escape to orbit.

No escape/rescue requirements are identified for Hazard 2.

Effects of Hazard 3, Impairment following Contamination

Contamination of cabin atmosphere will result in illness, incapacitation, or deprivation of oxygen if corrective action is not taken.

Corrective Measures for Hazard 3

Preventive measures:

1. Provide oxygen masks, emergency pressure garments and/or pressure suits, or separate pressure compartment and ECS, and immediate use of one of these, following detection of contaminants.
2. Monitor cabin atmosphere to detect contamination and initiate corrective action before illness, incapacitation, or oxygen deprivation can occur.

Remedial measures:

1. Don space suits and return to a safe haven in lunar orbit if contamination cannot be removed.
2. Crewmen suffering from breathing contaminated atmosphere must be provided clean air, a safe haven, and medical aid.

Escape/Rescue Requirements for Hazard 3

Rescue will be required if corrective measures are not taken to prevent illness or incapacitation.

Effects of Hazard 4, Explosion or Fire

An explosion or fire with an internal system such as a high-pressure gas storage vessel, pyrotechnic, or experimental device may damage vital sub-systems, rupture cabin walls, and injure or kill crewmen.

Corrective Measures for Hazard 4

Preventive measures:

1. The use of hazardous items should be minimized or eliminated by substitution where possible. Where such items are high-pressure gas storage

bottles, pyrotechnics, and hazardous experimental devices must be carried, they should be separated from the main cabin and from critical subsystem components by enclosing in vented compartments and structures designed to contain an explosion or fire.

2. Explosions in gas storage bottles should be prevented by reliable relief valves and by monitoring to provide warning of excessive pressures, plus use of manual procedures to vent a malfunctioning bottle.
3. Achieve reliability and safety by use of adequate safety factors (burst to operating pressure) in pressure vessel fabrication.

Remedial Measures:

1. In the event of fire or explosion, it should be possible to seal quickly each pressurized compartment separately, and then remotely exhaust the atmosphere of the compartment containing the fire or explosion. (See Page 2-26)
2. Fire extinguishers should be provided in each pressurized compartment of manned vehicles.
3. Oxygen masks and emergency pressure garments should be available in each pressurized compartment.

Escape/Rescue Requirements for Hazard 4

Escape and rescue will be required in the event of fire or explosion in a tug crew compartment on the lunar surface.

Effects of Hazard 5, Isolation of Crew Members on EVA Traverse

If the crew members in a tug on the lunar surface must return to orbit quickly for their own safety, they may have abandoned crew members away from the landing site on traverse. The crewmen on traverse will be isolated, with a limited life support stay time capability, and will require rescue from lunar orbit.

Corrective Measures for Hazard 5

Preventive measures:

1. All crew members on EVA should return to the tug without delay following notification of an emergency at the tug. This will minimize time delay **in returning to orbit**, if this action is chosen, and require only one set of rescue operations should rescue be necessary.
2. Emergency life support duration capability on board the lander tug should **always exceed the time required for return of all crewmen to the tug plus return to a safe haven in lunar orbit**. This capability must be established uniquely for each mission.
3. Use of two tugs for each surface mission such that a backup system is always available.

Remedial measures:

1. Provide life support and other necessities with the EVA crew on traverse calculated to assure a safe stay time exceeding rescue time. Perform a rescue mission.

Escape/Rescue Requirements for Hazard 5

Rescue will be required for crewmen abandoned while on traverse away from the lander tug.

Effects of Hazard 6, Inability to Fly the Tug in Pressure Suits

Inability to fly the tug and return to orbit in pressure suits, following loss of cabin atmosphere, will leave the crew stranded on the lunar surface to await rescue.

Corrective Measures for Hazard 6

Preventive measures:

Provide capability for operation and return of the tug to orbit by crewmen in pressure suits.

No remedial measures are identified for Hazard 6.

Escape/Rescue Requirements for Hazard 6

Rescue will be urgently required if crewmen are unable to fly the tug in pressure suits.

HAZARD STUDY 18
SUMMARY OF SAFETY GUIDELINE CANDIDATES

1. Each lunar lander tug shall be provided with two separate pressure compartments, with quick access from one to the other and with pressure suits (or emergency pressure garments) and PLSS's stored in each.
2. Each lunar lander tug shall be provided with emergency pressure garments which can be donned more quickly than full pressure suits.
3. Crewmen in a solo lunar lander tug on the lunar surface shall remain in pressure suits at all times if quickly accessible separate pressure compartments and emergency pressure garments cannot be provided.
4. The lunar lander tug must be flyable by crew members in pressurized space suits.
5. No subsystem failure in a lunar lander tug crew compartment shall deprive the crew of the ability to perform at least one of the following actions:
 - a. Replace or repair the failed article.
 - b. Return to a safe haven in orbit.
 - c. Await rescue.
6. A rescue vehicle should be standing by in lunar orbit at all times during a solo lunar lander tug mission on the lunar surface.
7. Cabin atmosphere shall be monitored continuously to detect contamination, and immediate action taken to use either oxygen masks, emergency pressure garments, pressure suits, or separate pressure compartment and ECS as appropriate if contaminants are present.
8. Oxygen masks, emergency pressure garments, and pressure suits shall be provided for use following detection of contaminants in cabin atmosphere. Availability of a second, separate pressurized compartment and ECS is also recommended.
9. Standard operating procedures shall require that crew members, on EVA traverse from a solo lunar lander tug, return to base without delay following notification of an emergency at the tug.

10. Emergency life support capability on board a solo lunar lander tug shall always exceed the time required for return of all crewmen to the tug plus return to a safe haven in lunar orbit. This capability must be established uniquely for each mission.
11. Each EVA crew on traverse shall be provided with life support and other necessities calculated to assure a safe stay time exceeding rescue time.
12. High-pressure gas storage bottles, pyrotechnics, and hazardous experimental devices shall be separated from the main cabin and from critical subsystem components by enclosing in compartments vented to space and structures designed to help control an explosion or fire.
13. Pressures in high-pressure storage vessels shall be monitored to provide warning of an impending explosion, and procedures shall be developed to correct potential hazards so detected.
14. Provision should be made for quickly sealing each pressurized compartment separately and then remotely exhausting the atmosphere to extinguish a fire. (See note Page 2-26)
15. Fire extinguishers shall be provided in each pressurized compartment of manned vehicles.

HAZARD STUDY 19

LOSS OF LUNAR SURFACE BASE (LSB) HABITABILITY DURING OCCUPANCY

INTRODUCTION

The lunar surface base will provide living and working facilities on the lunar surface for scientists and engineers conducting a wide variety of tasks over an extended period of time, and will provide support for lunar surface expeditions (Ref. 1).

This study analyzes hazards associated with a lunar surface base (LSB) that becomes functionally inoperable or uninhabitable either before or at the time of initial manning, or while manned.

ASSUMPTIONS

1. A lunar surface base has previously been taken to the lunar surface unmanned.
2. One or more fully operable lunar lander tugs with crew compartments are required to be at the surface base site at all times when the base is manned. The surface-based tugs provide alternate shelter capability, escape capability, and transportation to an orbiting lunar station for normal and emergency transport requirements (Ref. 2).
3. Access to the LSB crew compartment from the lunar surface will require an elevator, long ladder, or ramp.
4. Crew compartments are provided with contaminant detection and removal equipment.
5. All critical life support system components are highly reliable and have redundant parts.
6. The internal design, functions, and safety of the LSB are the concern of other studies, and are not examined here.

THE MAJOR HAZARDS

The major hazards identified are:

1. Insufficient time to don space suits or escape to an adjacent, safe compartment following sudden loss of cabin atmosphere. It is assumed this could happen only following a meteoroid strike, collision, or explosion that ruptured the cabin pressure shell.
2. Inadequate backup or emergency power and life support supply to allow time for subsystem repair, transfer to a nearby safe haven, or to await arrival of a rescue crew.
3. Illness or incapacitation or deprivation of oxygen following contamination of cabin atmosphere.
4. Injury following explosion or fire with an internal system such as a high-pressure gas storage vessel, pyrotechnic, or experimental device.
5. Loss of access from base to surface, or surface to base following damage to elevator, ladder, or ramp.

ANALYSIS OF IDENTIFIED HAZARDS

Effects of Hazard 1, Insufficient Time to Don Space Suits

Insufficient time to don pressure suits or escape to an adjacent, safe compartment following sudden loss of cabin pressure will result in loss of the crew.

Corrective Measures for Hazard 1

Preventive measures:

1. Escape to a separate pressurized compartment could normally be accomplished much more quickly than donning of a pressure suit. Action must be completed before cabin pressure drops to 1.7 psia (Ref. 3). Thus it is advisable to have multiple pressurized compartments available, with interconnecting passageway or airlock hatches open at all times but quickly sealable. According to Ref. 1, the LSB is to contain a separate compartment for survival in case of primary compartment failure.

The compartment(s) selected must have the capability to provide a safe haven for all crew members present until one of the following can be accomplished:

- a. The base failure can be corrected
 - b. The crewmen can move to the shelter of a lunar lander Tug crew compartment.
2. Provision of an emergency pressure garment that could be donned much more quickly than a full pressure suit would enhance the ability of a crewman to safely make repairs or reach a safe haven. This garment might be constructed of nylon or dacron polymer impregnated material which could be stored under inert conditions in a flat aluminum container with "rip-out" sealcovers. The emergency suit would be designed to operate directly off either the primary base atmosphere supply or bottled supply of the same gas mixture.

No remedial measures are identified for Hazard 1

Escape/Rescue Requirements for Hazard 1

Escape to a safe haven will be required, but there should be no need for rescue.

Effects of Hazard 2, Inadequate Power and Life Support Supply

Inadequate backup or emergency power and life support supply to allow time for subsystem repair, transfer to a nearby safe haven, or to await arrival of rescue assistance will result in loss of the crew following failure of a vital station subsystem.

Corrective Measures for Hazard 2

Preventive measures:

Each mission sequence must be planned such that a backup or emergency source of power, life support, and communication capability will be available at all times so that following loss of primary source, the crew can proceed to a safe haven unassisted or await rescue, whichever time is greater. It is assumed that lunar lander tugs, stationed 1 to 1 1/2 nm from the LSB, will always be available as a safe haven.

No remedial measures are identified for Hazard 2.

Escape/Rescue Requirements for Hazard 2

Rescue of a crew in a lunar surface base with inadequate power and life support supplies may be required if lunar lander tugs are not standing by as safe havens.

Effects of Hazard 3, Impairment following Contamination

Contamination of cabin atmosphere will result in illness, incapacitation, or deprivation of oxygen if corrective action is not taken.

Corrective Measures for Hazard 3

Preventive measures:

1. Provision of oxygen mask, emergency pressure garments and/or pressure suits, or separate pressure compartment and ECS, and immediate use of one of these, following detection of contaminants.
2. Monitoring of cabin atmosphere to detect contamination and initiate corrective action before illness, incapacitation, or oxygen deprivation can occur.

Remedial measures:

1. Outside assistance, or temporary abandonment of the station may be required if contamination cannot be removed.
2. Crewmen suffering from breathing contaminated atmosphere must be provided clean air, a safe haven, and medical aid.

Escape/Rescue Requirements for Hazard 3

Rescue will be required if corrective measures are not taken to prevent illness or incapacitation from contamination.

Effects of Hazard 4, Explosion or Fire

An explosion or fire may have hazardous effects similar to Hazards 1 and 3, plus the following:

1. High-pressure gas storage bottles, pyrotechnics, and hazardous experimental devices should be separated from the main cabin and from vital subsystems components by structures designed to contain an explosion or fire.

2. Pressures in high-pressure storage vessels should be monitored to provide explosion warning, and procedures developed to correct potential hazards.
3. Where multiple pressure compartments are provided in a system, crew members should not all occupy one compartment at one time.
4. Provision should be made in station design for sealing each pressurized compartment separately and then exhausting the atmosphere to extinguish a fire.
5. Fire extinguishers should be provided in each pressurized compartment.

Remedial measures:

Crewmen injured by explosion or fire will require immediate medical assistance, provision of pure atmosphere, and removal to a safe haven.

Escape/Rescue Requirements for Hazard 4

A crewman injured by fire or explosion must escape or be rescued and provided a safe haven and medical aid. Removal to Earth may be necessary for adequate treatment.

Effects of Hazard 5, Loss of Access between Surface and Base

Loss of access from base to surface, or surface to base, could result in entrapment of base crewmen, denial of access to base crewmen for assistance or rescue, and denial of a safe haven to EVA personnel returning to the base.

Corrective Measures for Hazard 5

Preventive measures:

The lunar surface base should be provided with alternate access ports and alternate access/escape routes. Alternate means for transporting incapacitated crewmen both from surface to base and from base to surface should be provided.

No remedial measures are identified for Hazard 5.

Escape/Rescue Requirements for Hazard 5

No escape or rescue requirements are identified.

SOURCE DATA REFERENCES

1. "Lunar Surface Base Project Description Document", AMPO, Manned Spacecraft Center, Houston, Texas; 15 June 1970
2. "Lunar Base Synthesis Study Plans - Monthly Progress Letter", 70 MA 7303, dated 14 October 1970, North American Rockwell, Downey, California
3. "Analysis of the Required Operational Characteristics of Space Escape Systems", Vol. III, J. E. Moeller, et al, North American Rockwell; November 1967, SAMSO-TR-67-7

HAZARD STUDY 19

SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. Provision shall be made to remotely activate and check out a lunar surface base which has been taken to the lunar surface by an unmanned lunar landing tug.
2. A crew sent to activate a defective unmanned lunar surface base shall be provided with pressure suits and PLSS units, repair parts and tools, portable battery powered lights, and specific procedures for inspection and repair.
3. Each lunar surface base shall have more than one pressurized compartment capable of supporting the crew. Hatches to interconnecting passageways or airlocks shall be kept open at all times, but be quickly sealable in an emergency.
4. Each lunar surface base shall have parked near the site space tug vehicles with crew compartments, propulsion modules, and instrument units capable of housing and supporting the entire base crew and escaping to orbit.
5. Each lunar surface base mission sequence shall be planned such that a backup or emergency source of power, life support, and communication capability is available at all times so that following loss of a primary source, the crew can proceed to a safe haven unassisted or await rescue, whichever time is greater.
6. Cabin atmosphere in a lunar surface base shall be monitored at all times to detect contaminants and permit corrective action to be taken before illness, incapacitation, or oxygen deprivation can occur.
7. Each lunar surface base shall provide oxygen masks and emergency pressure garments at each crew station, pressure suits and PLSS units for each crew member, and immediate use of these or escape to a separate compartment following detection of contaminants in the atmosphere.

8. High-pressure gas storage bottles, pyrotechnics, and hazardous experimental devices shall be separated from the main cabin of a lunar surface base, and from critical subsystems components by enclosing in compartments vented to space, and in structures designed to help control explosion or fire.
9. Pressures in high-pressure storage vessels shall be monitored to provide warning of an impending explosion, and procedures shall be developed to correct potential hazards so detected.
10. Where multiple pressure compartments are provided in a system, crew members shall not all occupy one compartment at one time.
11. Provision shall be made in lunar surface base design for quickly sealing each pressurized compartment separately, and then exhausting the atmosphere to extinguish a fire. (See Note Page 2-26)
12. Fire extinguishers shall be provided in each pressurized compartment of manned vehicles.
13. Each lunar surface base shall be provided with alternate access ports, alternate access/escape routes, and alternate means for transporting incapacitated crewmen from surface to base, and from base to surface.
14. Careful attention should be given to the use of non-flammable materials in the lunar surface base design, and the atmosphere provided should be two-gas. Hazardous materials should be handled in a specially designated area.

HAZARD STUDY 20

STUDY OF OPERATIONS IN AND AROUND THE LUNAR SURFACE BASE

INTRODUCTION

A lunar surface base constitutes a complex system having a large number of interactions analogous to a multi-loop feedback system. Activities that will occur in the establishment and operation of a lunar base will commence with delivery of site-preparation vehicles and materials, and will be followed by delivery, unloading, and location of the lunar base modules. Initial start-up and checkout of base systems will then occur through use of an umbilical, for example, connected to a tug on the surface acting as a temporary shelter for the initial crew. The crew will then begin lunar operations and conduct scientific and engineering studies as scheduled in the mission program. These activities will encompass base and vehicle (e.g., the rovers) ingress/egress procedures, layout of instrumentation - typified by setting up radio astronomy and X-ray telescopes - and a variety of rover and lunar flyer traverses to remote sites for exploratory purposes.

A nuclear reactor may be chosen for the generation of electrical power. The SNAP 8 system, supplying a nominal 35 kw of electrical power, is a likely initial candidate for this function. This study will assess the impact, from the potential hazards viewpoint, to the manned lunar mission of the presence of such a nuclear power system.

ASSUMPTIONS

1. From an orbiting lunar space station a crew will descend to the lunar surface in a tug and complete site preparation at the selected location for the lunar surface base.
2. The nuclear reactor power plant will arrive at lunar orbit and be delivered to the surface base area, prepared for operation and kept in a quiescent state until the lunar base modules have arrived and are set up, ready for checkout.
3. Auxiliary vehicles such as the rovers and flyers will arrive as scheduled in the NASA mission plans.

THE MAJOR HAZARDS

The major hazards identified are:

1. Damage to personnel shelters (i.e., the base) and injury to crew members by ejecta thrown up by the engine plumes of the tug as it nears the lunar surface.
2. Module handling leading to tip-over and injury or damage during arrival and location of lunar base modules.
3. Accident while handling and setting up large structures for research purposes while in an EVA mode.
4. Fire in a lunar surface base.
5. Release of fission products from the reactor after sustained full power operation.

ANALYSIS OF IDENTIFIED HAZARDS

Effects of Hazard 1, Damage from Ejecta

Tug rocket engine plumes will impinge on the lunar surface during landing or liftoff and give rise to ejecta from the surface which, in turn, could strike lunar vehicles parked nearby, the lunar base, or crew members in an EVA mode. Such strikes could injure EVA crew members and/or damage the base, thus imperiling life support for the crew.

Corrective Measures for Hazard 1

Preventive measures:

1. Locate tug landing areas away from the LSB, the optimum distance to be determined by study. Current studies suggest 1 to 1 $\frac{1}{2}$ nautical miles.
2. Prepare landing sites for the tugs at lunar surface base sites so as to prevent ejecta before and at touchdown or liftoff.
3. Forbid EVA activity near the base during tug landings or departures.

No remedial measures are identified for Hazard 1.

Escape/Rescue Requirements for Hazard 1

None are identified.

Recommendations for Further Study

It is recommended that studies be conducted to determine the optimum distance that tug landing areas should be located with respect to the LSB. Additionally, techniques should be evolved for assuring that there are no lunar ejecta due to plume impingement whenever tugs land or depart. That is, a method of preparing a permanent landing pad should be evolved. Minimum landing distance should then be a function of landing pad preparation.

Effects of Hazard 2, Module Tip-over

At least one mode of providing an LSB involves the "assembly" of a group of modules landed on the lunar surface. These modules would have to be moved to a common location, and this would be unnecessarily difficult if done unmanned. Some sort of rover would have to be used, and as a consequence the procedures of loading the modules, moving them to a selected location, and unloading them would present the potential hazard of tipping over and causing injury or death to one or more crew members. Tipping over could result from making too sharp a turn, striking and attempting to ride over a large rock, entrapping a wheel in a small crater, or from wheel or rover structural failure.

If the LSB is brought to the surface in a single unit, there still remains the task of locating and erecting scientific equipment, some of which is physically large and heavy, such as radio astronomy and X-Ray and optical telescopes. The modules for this equipment will also require location at specific sites other than their respective landing sites. The potential hazard noted above will exist in these cases also.

Corrective Measures for Hazard 2

Preventive measures:

1. The movement of modules once loaded aboard a "rover" could be conducted remotely by crew members traveling with, but not close to or aboard, the module carriers. The crew members could ride a separate rover far enough from the module to avoid it completely in case of tip-over, but close enough (i.e., leading it) to guide it around hazards.

2. Modules landed already emplaced on a rover would avoid loading on the Moon and would reduce the task to unloading only. If the modules arrive mounted on the chassis of a tracked or wheeled vehicle, then they can be driven to the set-up location and connected as required. Differential ground heights can be adjusted through the use of jacks which are mechanically fixed after adjustments to accommodate module connection at the final site for the LSB.

Remedial measures:

If a module tips over and strikes a crewman, he will be injured and will need a rover vehicle and stretcher to bring him to a safe haven where his injuries can be treated. If he is pinned beneath the module, a winch and cable combination or similar mechanism will be required to free him.

Escape/Rescue Requirements for Hazard 2

Should a module or other large piece of equipment tip over during its movement to an operational site and injure or pin a crew member to the surface, rescue will be necessary.

Effects of Hazard 3, Accident while Setting up Large Structures

The problems involved in setting up large structures for research purposes while in an EVA mode are essentially the same as those in Hazard 2, with the additional problem of avoiding entanglement with large structures like antennas (whether Yagi-type, or dish wide-mesh type, or multiple helices), or large solar arrays, or with wiring assemblies that form complex arrangements on the surface, or close enough to the surface to pose the entanglement hazard.

Corrective Measures for Hazard 3

Preventive measures:

1. All of the preventive measures of Hazard 2 apply.
2. Operations in setting up complex structural networks such as antennas should be designed so as to avoid having a crew member work (with his PLSS or other devices attached to him) in a back-to-back mode in order to avoid physical entanglement.

3. Laying out cable or wiring on the lunar surface in concert with setting up equipment should be accomplished so as to avoid foot entanglement. This may be done by burying cables or wires, by laying equipment and attached wires in a straight line or other pattern which avoids any but simple crossing (of the cable, etc.) during set-up/conduct of the experiment, or by stringing wires on poles.
4. Working in (at least) pairs, fellow astronauts can avoid entanglements by carrying equipment, cables, wiring between them, and so avoid draping these over one man with the inherent possibilities of becoming ensnared.
5. When working at substantial distances from the LSB, a small shelter with supplies and first aid equipment should be available on site. This shelter could be a cabin rover.

Remedial measures:

Complex structures should be moved and set up by astronauts working in groups, at least in pairs - the buddy system - in order that aid will be immediately available in the event of a mishap.

Escape/Rescue Requirements for Hazard 3

An astronaut entangled in cabling, wiring, or complex structure may need aid to free him.

Effects of Hazard 4, Fire

During the course of conducting experiments, or of performing maintenance/repair functions in the lunar surface base, inadvertent crossing of wires, short circuits, accidental mixing of hypergolic chemicals, inadvertent detonation of pyrotechnics, and similar incidents might lead to a fire.

A fire in the LSB is very serious since a fire of any consequence will leave little time for remedial action before the affected compartment(s) is heavily involved. The effects of a fire include injury or death of crew members, destruction of equipment vital to the life support of crew members, and failure of the pressure shell of the compartment, thus exposing the crew to the vacuum and a severe temperature decrease in the affected compartment.

Corrective Measures for Hazard 4

Preventive measures:

1. Very severe requirements for non-combustibility of materials used in constructing the LSB should be imposed to the maximum extent possible.
2. To the maximum extent practical:
 - a. Relegate all handling and storage of hypergolic chemical combinations to a separate lunar shelter, or rule them out of use in the LSB altogether.
 - b. Minimize handling and use of pyrotechnic devices inside the LSB.
 - c. Use "trays" to carry wiring and cables totally separated from traffic so as to minimize damage by collision, entanglement, wetting by chemicals, etc.
 - d. Use a two-gas atmosphere, oxygen and nitrogen, so as to have a heat-absorbing diluent.
 - e. In order to avoid the need for soldering wiring, all wire connections should be arranged through the use of fasteners. This general philosophy should be applied throughout the LSB to connecting plumbing, structures, etc.
 - f. Fluids used in the LSB cooling system should be totally non-combustible, even in pure oxygen.
 - g. Smoking by any personnel should be completely forbidden.
 - h. If propellants are stored on the lunar surface, they should be kept well removed from the LSB so that an accident (explosion, etc.) involving the stored propellants does not propagate to the base.

Remedial measures:

1. The LSB should be designed so that it is divided into two or more isolatable compartments. An optimum distribution of space suits and portable oxygen masks should be determined. Then compartments involved in fire can be vented or flooded with nitrogen (or CO₂ stored from metabolic waste) while the crew takes refuge in a safe compartment and attempts to control the fire and damage from this safe area.
(See note Page 2-26)

2. A compartment involved with fire could be flooded with nitrogen and simultaneously vented while keeping pressure at some specified level. This can be done with the crew wearing portable oxygen masks.
3. Development of special fire extinguishers which would minimize or have zero contaminants resulting from use of such an extinguisher is recommended.

Escape/Rescue Requirements for Hazard 4

1. The crew of an LSB damaged by fire can leave it and return to lunar orbit via a tug which is parked nearby on the lunar surface.
2. If crew members are in a closed isolated compartment without direct access to the outside (i.e., without passing through the fire-involved compartment) they will have to be rescued.
3. If the LSB has a fire, EVA astronauts will either be able to go to a parked tug or, if they are needed, assist in extinguishing the fire and aiding crewmen in the base.
4. Astronauts out on a rover or flyer traverse will have to be informed of the fire; they then may:
 - a. Return (if they are close by) to fight the fire and render assistance
 - b. Return to the LSB and take the tug to lunar orbit.
 - c. Agree to rendezvous at some selected point for rescue.

Effects of Hazard 5, Nuclear Radiation

A lunar surface base may draw primary electrical power from a nuclear power supply. The most severe nuclear power accident source which might be considered credible is the release of fission products from the reactor-shield assembly after sustained, full-power operation (Ref. 1). Such an event might be initiated by a leak in the primary NaK loop which would result in NaK boiloff. This could cause partial - and perhaps complete - meltdown of the core due to afterheat generation. This would lead to fission products escaping from the power plant. It is believed reasonable to expect that most of the fission products would be confined to the immediate location of the power plant.

The consequences of the postulated accident have been estimated, based on occurrence after one year of sustained operation at a thermal power of 400 kw. The gamma ray source strength data were obtained from additional references given in Ref. 1, and the separation distance required to limit the integrated dose to 50 REM in a 14-day period was calculated for various degrees of fission product release. The results are given in Table I.

Table I
Postulated Accident Occurrence (Ref. 1)

Case	Separation distance req'd for 50 REM in 14 days (ft)	14-day dose at 200 ft (REM.)
1. All fission products released from shield, but contained with vehicle that landed the power plant	2,000	50
2. Only gaseous fission products released from shield, but contained within landed vehicle	900	10
3. All fission products released, but contained within shield	900	10
4. Only gaseous fission products released, but contained within shield	400	2

The information in Table I is sufficient to indicate that only lack of knowledge of the nuclear accident would endanger any member of the LSB crew to any substantial degree, since he could conceivably walk into the irradiated area.

A consequence as serious as irradiation is the loss of electrical power for the LSB in the event of power source failure. The loss of many functions will occur if power fails. Such a loss could place the LSB crew in jeopardy because of the cascading effects on life support, communications, and other subsystems.

Corrective Measures for Hazard 5

Preventive measures:

1. A series of strategically placed counters and dosimeters (for gammas, neutrons, and other possible particles) in an alarm circuit would provide a constant warning system for the LSB so that radiation levels just outside the nuclear power plant, and at selected distances from it, could constantly be monitored and the crew warned of hazardous conditions.
2. Delivery of the power plant as a unit permanently emplaced in a landing vehicle and landed inside a designated crater is suggested as a delivery mode to minimize hazards in both delivery and operation. Alternately, a scraper blade on a large lunar rover could cut out a ramp to a designated crater, and the palletized or skid-mounted power-plant-in-vehicle could be towed down the ramp into the selected crater; the breached crater wall would later be reconstructed before reactor start-ups. Reference 1 states that a power plant emplaced on a lunar landing vehicle can be designed so that only minor tasks remain before startup of the reactor. The emplacement in a crater reduces the radiation hazard to the crew of the LSB to a great degree.
3. In order that the crew not be faced with the consequences and hazard of no electrical power in the event of power plant failure, a tug should be parked near the LSB for evacuation and return of the crew to the lunar space station.
4. An alternate to No. 3, above, is the provision of secondary (emergency) power sources usable until primary power is restored. The provision of such second sources should be a certainty.
5. Another alternative, whose study ought to be considered, is the provision of not one, but two nuclear power plants for the LSB. If used, these should be widely separated, and each run at half-power, whereupon the immediate availability of one is at hand should the other malfunction. The costs implied, as well as the inherent advantages of such a system, must be considered.

Remedial measures:

1. Remedial measures for serious radiation exposure probably implies return to Earth for treatment, whereas minor exposure is likely to be treated at the LSB or at the lunar space station.
2. Repair of a malfunctioned nuclear power source is discussed at length in Reference 1. Suffice it to state here that, at least in the early years of operation, capability for repairs will be rather limited.

ADDITIONAL INFORMATION

Some ideas on lunar surface base configuration that improve safety are presented in Appendix E, Supplemental Data Report No. 3.

SOURCE DATA REFERENCES

1. Design Requirements for Reactor Power System for Lunar Exploration; LMSC/677879, Vol. II, LMSC, Sunnyvale, Calif., September 1967
2. Space Tug, Logistic Vehicle Parameters; North American Rockwell, 7OMA5828, July 1970, pp 19 - 27
3. Lunar Base Synthesis Study - First Interim Progress Report; North American Rockwell, October 1970
4. Lunar Staytime Extension Module; Goodyear Aerospace Co., GER-12246
5. Internal Memo: NASA Headquarters, Gangler to Goldberg, October 1966
6. LESA Deployment Procedures, LMSC/A665606; LMSC, Sunnyvale, Calif. February 1965

HAZARD STUDY 20
SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. Landing pads should be prepared for tugs visiting a lunar surface base at the earliest possible time after initiating LSB activity.
2. The movement of large pieces of equipment, or of modules, on the lunar surface should be accomplished with the astronaut nearby and guiding and controlling such movement, but not aboard the carrying vehicle. Thus, in the event of module transport vehicle upset, tip-over, etc., he will not be trapped or injured.
3. The buddy system, or presence of a safety man, should be used in setting up large equipment on the lunar surface, so that EVA astronaut entanglement (e.g., wires) is minimized as a hazard, and so that immediate aid is available if needed.
4. Very severe requirements for use of non-flammable materials used in lunar surface base construction should be observed.
5. Enough tugs should always be available at a lunar surface base to evacuate the entire crew to lunar orbit should the LSB have to be abandoned.
6. The following items are forbidden in, or very close to, the LSB:
 - a. handling or storage of hypergolic fluids
 - b. handling or storage of pyrotechnic devices
 - c. combustible fluids in the thermal control system
 - d. dangerous chemicals
 - e. bacteriological experiments
7. A fire extinguishing system should be designed to flood any fire-involved compartment with nitrogen or other non-combustible gas. A fail-closed vent system should be used in concert with the fire extinguishing system to rid an involved compartment of contaminants.
8. Space suits and PLSS's should be readily available at strategic locations in the LSB for use in emergencies.

9. Crew smoking shall be prohibited at all times on lunar missions.
10. A nuclear power source used to generate electrical power shall be stationed at least 2,000 feet from the LSB -- preferably in a crater whose walls are higher than the reactor container, and that have been thickened by moving soil.
11. Secondary power sources should be available for the LSB in the event of nuclear source malfunction. Such secondary sources should be adequate to maintain all life support and essential communications functions until repairs are made, or rescue or return to orbit effected.
12. Life support umbilicals for oxygen, communications, power, contaminant and thermal control, etc., shall be provided at selected areas of the exterior of the LSB. These shall be adequately marked and lighted at night. Moreover, an internal display panel shall indicate actual use of each such umbilical.
13. It is recommended that the LSB have provisions to permit shirtsleeve transfer to and from the cabin rover.
14. The airlocks, doors, hatches, elevators, etc., for the LSB shall be large enough to accommodate at least one stretcher case, plus one crewman wearing a total EVA mobility unit.

HAZARD STUDY 21
ACCIDENT OR IMPAIRMENT TO A ROVING VEHICLE

INTRODUCTION

Major safety concerns associated with lunar surface operations occur as a result of hazards imposed by critical roving vehicle subsystem failures. Major subsystems that will be considered are mobility, navigation and life support. Communications are discussed elsewhere. In addition to mechanical or electrical failures of major subsystems, vehicle impairment due to accidents will be considered, e.g., collisions or immobilization due to some physical lunar surface "trap."

These hazards will be discussed for two major classes of lunar vehicles:

1. Small, non-cabin, rovers with short range capability where life support is provided by portable life support backpacks.
2. Large, cabin type rovers with long range capability and life support provisions which permit a shirtsleeve environment within the cabin.

ASSUMPTIONS

1. Small, non-cabin rovers will operate within walk-back range of a shelter.
2. Large cabin type rovers will operate beyond walk-back range of the lunar base of operations.

THE MAJOR HAZARDS

The major hazards identified are:

1. A lunar rover vehicle is immobilized due to a mobility subsystem failure or physical entrapment, stranding the crew beyond walk-back distance.

2. A failure associated with a lunar roving vehicle navigation subsystem isolates the crew.
3. A system failure on a lunar roving vehicle deprives the crew of life support.

ANALYSIS OF IDENTIFIED HAZARDS

Effects of Hazard 1, Crew Stranded Beyond Walk-back Distance

1. Vehicle mobility failures affect astronaut safety differently as a function of distance from a safe shelter. If small, non-cabin vehicles are incapacitated by a mobility failure, the astronaut(s) should be able to walk back to the shelter, based on the assumption that lunar sorties for these small vehicles are limited in range accordingly. Immobilization of large, cabin type vehicles presents the danger of stranding two or more astronauts beyond walking distance of a safe shelter. Furthermore, the possibility should be considered that the vehicle immobilized due to an accident may injure the astronauts, as well as the vehicle.

Corrective Measures for Hazard 1

Preventive measures:

1. Vehicle Design - The large cabin rovers should be designed to contain both a primary driving station in the forward cabin area and an emergency redundant driving station in the aft airlock area. In addition, the primary driving station should be designed for a two man "pilot/copilot" operation with one man able to conduct all essential functions in an emergency mode operation. Similarly, two man small non-cabin rovers should be operable by one man, but permit vehicle control takeover by either of the two crew members.

Other safety design features include:

- a. Incorporation of a roll bar in cabinless rovers to prevent injury to the astronaut in the event of vehicle overturn.
 - b. Incorporation of terrain slope warning indicators at the driver's station to inform the astronaut that the slope being attempted is approaching the limits of the vehicle's capabilities.
 - c. **Seat and shoulder restraints** for adequately securing the astronauts to their stations over "rough" terrain.
2. **Lunar surface hazard detection** - The possibility exists that a rover could become immobilized by dropping into a crater or through a weak crustal surface. In the former case, preventing is largely accomplished by providing adequate forward unobstructed visibility and illumination aids, as required. The latter case may require hidden cavity sensors installed on booms as illustrated in Fig. 1.

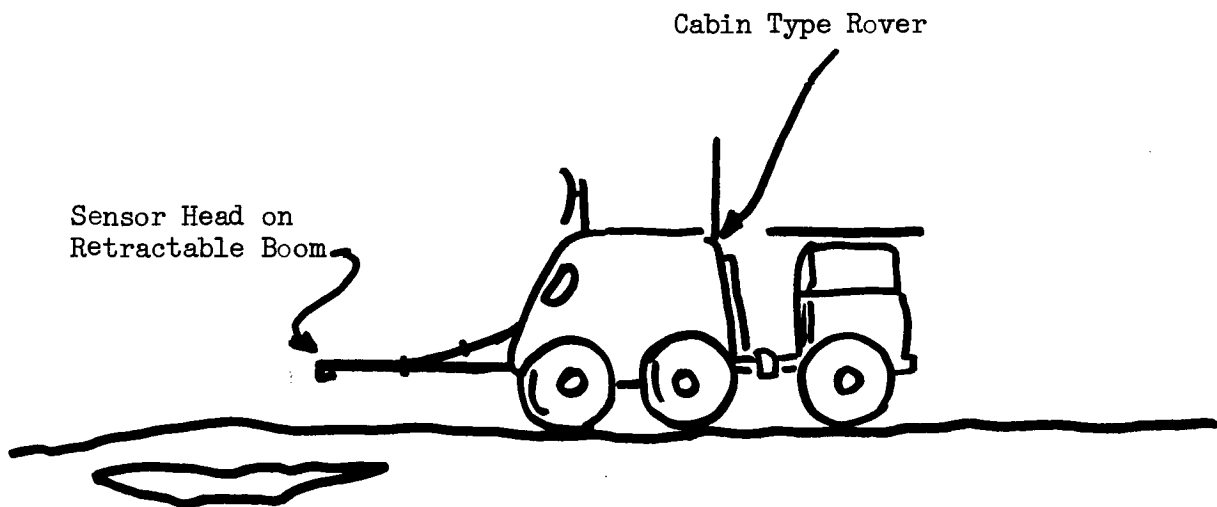


Fig. 1 Hidden Cavity Sensor Concept

3. Planning traverses to reduce hazards - Traverse planning that makes maximum use of the roving vehicle's capability to accomplish the scientific goals of the mission must also consider ways to reduce the hazards of exploration. Traverse paths can be designed to minimize distance from a safe haven. For example, a circular traverse, starting from a base located on the periphery of the circle, separates the vehicle from the base for a much greater extent of the traverse than one in which the base is located within the center of a planned circular traverse.
4. Multiple vehicle expeditions - Another approach which reduces vehicle distance from a safe haven is to employ two vehicles making simultaneous traverses which complement each other. Although each vehicle would explore different territories, the distance from one vehicle to the other would be less than that of either vehicle to the lunar base from which the expedition originated. In this manner each vehicle would serve as a redundant support and rescue vehicle for the other in the event of an emergency.
5. Supply caches - Another means for reducing the risks of being immobilized and isolated beyond a safe walk-back distance is to establish a series of depots containing a variety of life support/mission extension equipment. These depots could be strategically located at various points along the lunar traverse so that at no point would the astronauts be beyond walking distance from one depot to the other. Typical items that might be stored in such depots would include: Food, water, spare backpacks, fuel cells, batteries, medical supplies, radio and communication equipment, navigational aids, and critical vehicle spares.

Remedial measures:

1. Each crew on traverse should carry redundant communication equipment, radio beacons, and visual signal devices to aid in rescue.

Escape/Rescue Requirement for Hazard 1

If a lunar rover crew is stranded beyond walkback distance, rescue will be required.

Effects of Hazard 2, Isolated Crew

Navigation system failures could lead to deviations from predetermined traverse plans with a resultant lengthening of the mission beyond available supplies of expendables, i.e., fuel and life support provisions. Lack of "true" information regarding the position, heading and distance from a lunar base of operations will also hamper rescue operations.

Corrective Measures for Hazard 2

Preventive measures:

The navigation back-up should be independent of the ability to communicate. In addition, crewmen out on a lunar traverse should be provided with visual and auditory signalling aids to help rescue parties locate their position. These aids should consist of such items as rocket rescue beacons, deployable emergency antennas, reflecting sphere (visual and R F) and position indicator flags. Similarly, the base should radiate visual and auditory signals to facilitate a correct and expeditious emergency return to base. Depending on the point at which a navigation system failure occurs, and the available fuel reserves, the most advantageous course of action may simply be for the vehicle to retrace its path back to the lunar base. There should be no problem in visually following tracks made on the lunar surface since lunar surface characteristics (tracks) are very stable.

Remedial Measures:

Each crew on traverse should carry redundant communication equipment, radio beacons, and visual signal devices to aid in rescue.

Escape/Rescue Requirements for Hazard 2

A rescue mission will be required to retrieve those astronauts who have been stranded due to navigation errors.

Effects of Hazard 3, Loss of Life Support

Failures associated with the large rover cabin life support system will cause an abort of a lunar traverse mission and may jeopardize the lives of crewmen should backup systems be depleted before rescue or a return to base can be effected. Failures associated with portable life support systems utilized with small cabinless rovers are discussed in Hazard Study 23.

Corrective Measures for Hazard 3

Preventive measures:

Life support system failures may arise which lead to the contamination of the cabin atmosphere, or loss of pressure or discontinuity in the supply of breathing gases. In each of these cases, the astronaut should don his space suit and rely on a suit loop supply for the abort mode return back to base. A second level of redundancy would consist of utilization of available portable life support systems. An airlock, or dual safe compartment, is important in allowing the astronauts time to don their space suits. Additionally, if the airlock contains an emergency driving station, the astronauts can seal off a main compartment which is contaminated or ruptured and proceed back to the base by operating the large rover from the airlock emergency station.

Remedial measures:

1. Timely external assistance to provide life support.

Escape/Rescue Requirements for Hazard 3

A subsystem failure which brings life support capability to less than that required to reach a safe haven unassisted will have caused a requirement for rescue.

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HAZARD STUDY 21
SUMMARY OF SAFETY GUIDELINE CANDIDATES

1. The use of two independent vehicles, each capable of assisting the other should an emergency occur, is recommended for long traverses with cabin-type rovers. Each rover must be capable of returning all crewmen to a safe haven.
2. Non-cabin lunar surface rovers shall not operate beyond walk-back distance to a safe haven, unless such rovers are operated in pairs with each capable of supporting the other and returning all crewmen to a safe haven.
3. All lunar surface rovers shall be capable of operation, driving, life support, communication, etc., with crewmen wearing pressurized suits.
4. Each roving vehicle shall be completely operable and drivable by a single crewman.
5. It is recommended that an emergency driving station be provided in the airlock of cabin-type rovers.
6. Methods and devices for detecting hidden cavities in the lunar surface ahead of a moving lunar rover should be developed.
7. A series of depots or caches where critical supplies are stored along a planned lunar traverse route shall be considered in mission planning.
8. Navigation aids to lunar surface crews shall be capable of continuing operation even in the event of complete communications loss.
9. Lunar surface roving vehicle design features should include lap belts and shoulder restraints, roll bars or similar protection from injury in the event of vehicle overturn, and surface slope warning indicators.
10. A rescue plan shall be available in detail prior to each operational surface traverse mission.
11. Doors, hatches, and airlocks on cabin-type roving vehicles shall be capable of accommodating a stretcher case plus a fully suited crewman.
12. Lunar surface rovers shall carry redundant communications equipment radio beacons, and visual and auditory signalling devices to aid in rescue.
13. Roving traverses should be planned to minimize distance from a safe haven while making maximum use of the vehicle's capability to accomplish scientific exploration.

HAZARD STUDY 22

PERSONNEL ACCIDENT OR IMPAIRMENT DURING SURFACE EVA

INTRODUCTION

The performance of tasks on the lunar surface associated with a transient or permanent lunar base will involve EVA operations and there will be astronaut interfaces with a wide spectrum of equipment and vehicles. These include:

- a. Scientific equipment emplacement and operation, frequently at distances exceeding two miles from the base.
- b. Lunar base and lunar vehicle maintenance, servicing, and repair.
- c. Deep drilling for subsurface cores in connection with seleneological studies.
- d. Operating open rovers and lunar flyers.
- e. Loading modules and/or equipment onto or off of vehicles.

Potential hazards associated with the extravehicular mobility unit (EMU) are discussed in Hazard Study 23. Hazards due to the presence of lunar dust are discussed in Hazard Study 32 while the problems of lunar surface visibility and communications are discussed in Hazard Studies 26 through 30.

ASSUMPTIONS

1. The buddy system in EVA is not considered to be limited to astronauts in pairs.
2. A malfunction in one astronaut's primary communication system (with the base) during EVA will not be cause for returning to base so long as he can communicate with his 'buddy' astronaut. Failure in both of their primary communications systems will be sufficient cause for mandatory return to base.

3. For activity more than one mile from the base EVA astronauts will normally use a vehicle to take them to the site of the activity.

THE MAJOR HAZARDS

The major hazards identified are:

1. Malfunction of life support system.
2. Sudden illness leading to nausea and/or vomiting (this hazard is dealt with in Hazard Study 35).
3. Entanglement with equipment (this hazard is dealt with in part in Hazard Study 20).
4. Injury resulting in bone fracture or flesh wound.
5. Rover or flyer accident leading to Hazard 4 plus unconsciousness.
6. Contamination by fluid that is corrosive to space suit or suit parts.

ANALYSIS OF IDENTIFIED HAZARDS

Effects of Hazard 1, Life Support System Malfunction

The effects of a life support system (LSS) malfunction could include loss of thermal control, denial of oxygen or metabolic water, failure to remove contaminants, or a combination of any of these events. They are all serious, although the loss of oxygen must be considered critical. The loss of any of the functions for any length of time would result in illness, at least, while the denial of oxygen would result in the loss of the astronaut.

Corrective Measures for Hazard 1

Preventive measures:

1. An emergency supply of oxygen should be available for each astronaut to permit him to get to a safe haven in the event of malfunction of his main supply. The option of manually activated supply for the emergency oxygen should be given the astronaut.

2. An emergency power supply should be available to run essential functions for life support long enough for the astronaut to get to a safe haven in the event of primary power supply failure.
3. An emergency contaminant removal supply should be available under the conditions as for item 1 above.

Remedial measures:

1. The buddy system should always be used so that short term supplies are available; that is, the astronaut whose system has malfunctioned should be able to plug into his fellow astronaut's LSS.
2. Any failure in the LSS should require an immediate, mandatory return to a safe haven.

Escape/Rescue Requirements for Hazard 1

1. The buddy system provides an escape method from the LSS malfunction although only for a limited time.
2. If anything but the oxygen portion of the LSS malfunctions there exists some limited time for rescue.

Hazard 2 is discussed in detail in Hazard Study 35 and not repeated here.

Effects of Hazard 3, Entanglement with Equipment (See Photograph on following page)

1. Setting up structures such as large antennas or working with deep drilling equipment (e.g., depths of 200-300 meters) or erecting temporary shelters during an extended traverse, or laying out many pieces of equipment all connected to a single power source, thus yielding a wiring network on or near the surface, all lead to the problem of keeping equipment worn or the astronaut himself from becoming entangled. If the astronaut is working alone, entanglement could lead to injury or worse if the astronaut is isolated and trying to free himself. Depletion of

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Hazards of Entanglement with Equipment - Apollo 14 Mission

consumables is another danger faced if an astronaut is entangled and isolated; this could cause illness, or injury or loss of the crew member.

Corrective Measures for Hazard 3

Preventive measures:

1. Erection of all structures on the lunar surface should be made automatic insofar as is reasonable.
2. Wiring should be laid out so as not to form a 'net'. Scientific instrumentation should be strung out and wiring buried where feasible.

Remedial measures:

1. By virtue of the buddy system one astronaut can disentangle another.
2. As a measure to be used when a danger is imposed by not disentangling immediately, an EVA astronaut should have a pair of heavy duty wire cutters with which to free himself.

Escape/Rescue Requirements for Hazard 3

If an astronaut becomes entangled and is not working under the buddy system concept, he will have to be rescued.

Effects of Hazard 4, Injury Resulting in Fracture or Flesh Wound

Involvement with the movement, emplacement, and/or erection of large and massive structures or instruments could lead to tip-over or collapse with resultant injuries to crew members involved in setting up these instruments/structures. Fractures or flesh wounds are likely in such events. Although suit rupture in such accidents is also possible, it should be recognized that fractures and bruises could occur without suit damage.

Corrective Measures for Hazard 4

Preventive measures:

1. All of the preventive measures recommended for Hazard 3 are applicable.
2. The construction, erection, emplacement, etc., of all proposed lunar structures/instrumentation should be practiced on Earth without omitting any steps (i.e., a complete training program) in order to uncover any difficulties that could arise on the moon and thus correct them before the lunar mission is initiated.

Remedial measures:

1. A portable lunar shelter should be available in the event the subject emplacements are distant from the base so that a fellow astronaut can supply first aid in the event of accident. A cabin rover should be very suitable in lieu of a portable lunar shelter. Splints and other first aid items should be included as standard equipment in rovers and other lunar shelters.

Escape/Rescue Requirements for Hazard 4

1. If an astronaut is seriously injured he will have to be brought back to the LSB or to the lunar space station or to Earth for treatment of his injuries.

Effects of Hazard 5, Accident Leading to Unconsciousness

1. The effects of adding unconsciousness to injury (as in Hazard 4) makes it necessary to move the injured astronaut without his cooperation. This procedure will place a burden on the other crew members engaged in activity at the accident site. Should the astronaut happen to be alone when injured and unconsciousness ensues, then he could be lost.

Corrective Measures for Hazard 5

No preventive measures are identified.

Remedial measures:

1. A prime measure here is mandatory use of the buddy system so that an unconscious crew member can receive immediate attention and so that the buddy can contact the base to prepare for receipt of the injured astronaut and to possibly render aid.
2. A means for a single crew member to move an unconscious buddy is required; for example, a stretcher that could be dragged or wheeled to the cabin rover and hand-winched up a portable ramp into the rover. Such a measure prevents the on-site loss of the astronaut.

Escape/Rescue Requirements for Hazard 5

1. Should the on-site crew not be able to render first aid and/or move the unconscious crew member to safety a rescue will be necessary.

Effects of Hazard 6, Contamination by Corrosive Fluids or by Lunar Dust

1. Various corrosive fluids will be used in the lunar complex and particularly at the LSB. Some of these fluids are hypergolic and may react with spacesuit material or materials identified with nearby equipment. These oxidation reactions are violent and therefore pose a danger to any EVA astronauts engaged in handling these fluids. Skin, flesh, and eye injuries are likely if contact is made with corrosive fluids. Should the spacesuit be attacked by the fluids then the astronaut's life support system integrity will also be endangered with evident and serious consequences.

When lunar dust is kicked up by walking EVA astronauts the dust exhibits a very strong tendency to adhere to the boots and spacesuits of the crewmen. Such dust gets into joints of the spacesuit and abrades their seals thus leading to increased leakage of the suit-contained atmosphere. If the dust is tracked into a lunar shelter or lunar vehicles it permeates the atmosphere and yields a considerable irritant to the respiratory systems of the crewmen. In addition, it settles on display-control panels and other equipment, posing an abrasive hazard to that equipment.

Corrective Measures for Hazard 6

Preventive measures:

1. Detailed consideration should be given to the substitution of passive fluids in place of the corrosive ones, assuming that such substitution does not compromise, to any serious degree, the functions of those fluids.
2. Hazardous fluids should be handled by EVA astronauts wearing protective overgarments to ensure that neither fluid nor fumes contact his spacesuit, boots, etc. The overgarment would be discarded before entering a shelter. In order to protect against lunar dust 'invasions' similar overgarment use should be initiated.
3. There should be a very strongly enforced rule indicating storage of all corrosive fluids at a (determined) safe distance from the surface base or shelter.
4. No EVA astronaut should be near any surface or space vehicle - unless he is aboard - during the initiation of motive power in order to avoid contamination by corrosive fumes.
5. Astronauts using the lunar flyer will need some protective garment to keep the exhaust fumes from contaminating their spacesuits, boots, and equipment.

Remedial measures:

1. An EVA astronaut injured by corrosive fumes will need immediate medical attention, therefore, appropriate first aid kits should be available and

a temporary lunar shelter in which to apply such first aid. The cabin rover would serve as an excellent lunar shelter.

Escape/Rescue Requirements for Hazard 6

1. An EVA astronaut seriously injured by corrosive fumes that cannot be treated out on some traverse will have to be rescued for treatment at the base or shelter. If surface facilities are insufficient, return to lunar orbit or Earth for treatment may be required.

ADDITIONAL INFORMATION

It is recommended that studies be conducted to consider alternatives to the use of corrosive fluids in the lunar complex. The extent of functional compromise and delta costs should be considered in such studies as well as the safety advantages to be gained in the use of such alternate fluids.

RECOMMENDED ADDITIONAL STUDY

In the event of nausea accompanied by vomiting it would be critically important to be able to reach past an astronaut's face plate to remove solids from the area in and around his mouth and nostrils. The kind of device suggested constitutes a flexible, globular (when inflated) glove box that could be fitted over the affected astronaut's head and made pressure tight at his neckband. It is suggested that further studies be conducted in this area to ascertain the value and form of such a device.

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5. One Man Lunar Flying Vehicle, Bell Aerosystems Report No. 7335-950012,
July 1969.

HAZARD STUDY 22
SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. Emergency oxygen supplies should be readily available to an EVA astronaut in the event of failure of his primary system.
2. The buddy system, or presence of a safety man, should be mandatory for EVA astronauts under normal conditions unless they are within a few tens of meters of the LSB or of the cabin rover or of the landed tug, and standby help is immediately available.
3. All EVA spacesuits should be designed to permit a fellow astronaut to plug in on another's life support system in the event of failure of his own LSS.
4. Failure or degradation of his life support backpack should make return to a safe haven mandatory and immediate for an EVA astronaut.
5. Erection of large structures/instruments should be automatic insofar as is reasonable without seriously compromising function or costs for the lunar complex.
6. For long distances or long-duration traverses, a temporary lunar shelter should be available for EVA astronauts in which to take refuge in the event of accident, injury, or other undesirable incident. Among supplies in such shelters should be - as a minimum - splints and first aid kits.
7. A means shall be provided for a single astronaut to move an unconscious EVA astronaut from an accident location to a nearby safe haven.
8. All corrosive fluids should be handled by EVA astronauts wearing a protective overgarment and protective boots or boot covers.
9. No EVA astronaut should be outside and in the immediate vicinity of any vehicle on the lunar surface during the initiation of motive power.
10. EVA astronauts using the lunar flyer should wear a protective garment during the interval that the flyer's engines are turned on in order to prevent contamination from engine exhaust.

11. Repair kits, analogous to the tire repair kit, should be available for all EVA astronauts (in general, for all suited astronauts) in order to be able to repair minor and medium suit leaks. Means should be provided for determination and location of leaks.
12. Decals that can easily be read by EVA crewmen should be provided to identify equipment function. Identification should also be provided for each EVA crewman so that he can be 'recognized' in video transmission.

HAZARD STUDY 23

HAZARDOUS OPERATIONS WITH EXTRAVEHICULAR MOBILITY UNITS

INTRODUCTION

This section considers hazards to the astronaut associated with failures of the EMU on the lunar surface. These hazards can be generated from three sources: failure of space suit/back-pack components, deleterious lunar environmental effects on the EMU, or operational astronaut accidents which inflict damage on the EMU.

ASSUMPTIONS

For the purposes of this analysis it is assumed that lunar surface extra-vehicular operations will be conducted in three basic contexts:

- a. In the immediate vicinity (walking distance) of a lunar base.
- b. Small excursions from a lunar base by means of a small cabinless lunar rover.
- c. In association with a large lunar roving vehicle with mobility and habitability provisions.

The time frame for this analysis is the 1980-90 period. Certain advances in the suit/back-pack state-of-the-art, explained below, are postulated.

THE MAJOR HAZARDS

The major hazards identified are:

1. Suit rupture. Suit integrity may be compromised by the following factors:
 - a. Operational accidents - falling off boarding/debarking ladder, vehicle overturning, tripping over natural object or emplaced scientific equipment, rupture of glove or suit due to harsh contact with system hardware.

- b. Suit deficiencies: e.g., oxygen leaks through defective seals, breakage of cable connecting EVA glove to wrist (Apollo 14).
- c. Inadvertent disconnection of back-pack hoses.
- d. Environmental hazards such as meteorite penetration.

2. Back-pack failure

- a. Communications or telemetry
- b. O₂ supply/pressurization
- c. Thermal control including either the oxygen circulation system in the PGA or water circulation system in the LCG.
- d. Carbon dioxide removal
- e. Odor and contaminant removal
- f. Humidity control
- g. Power failure.

- 3. Interruption of Life Support Provisions during Back-Pack Switching
Back-pack switching in the lunar vacuum environment involves the potential threat of interrupted life support provisions if the transition is not effected properly.
- 4. The loss of the face mask's heat/glare reflective coating which is essential for eye protection.

ANALYSIS OF IDENTIFIED HAZARDS

Effects of Hazard 1, Suit Rupture

Small suit ruptures may cause mission interruption at most and constitute a minor hazard only - as discussed below. A medium leak, as defined below, does demand immediate attention. A large rupture, however, would be very serious. Depending on the particular rupture and concurrent leak rate, loss of consciousness can occur in 20 seconds. The death of an astronaut could occur in 3 to 5 minutes, depending on the size of suit rupture and the ability of the back-pack to sustain oxygen supply and pressure.

Corrective Measures for Hazard 1

Preventive measures:

Prevention of potential catastrophic suit damage requires a consideration of two approaches:

1. Improvements in space suit design which can be expected to take a number of forms:
 - a. The greatest current need is for increased capability in mobility in a suited astronaut. Additionally, astronauts must have improved visibility and decreased suit encumbrances. At present, the protective envelope provided by the suit negates most cutaneous sensitivity cues. Consequently, the astronaut is not aware of objects brushed against until he is snagged or comes into hard contact with such object. Means for providing contact cues to the suited astronaut should be investigated.
 - b. Other suit improvements to be considered for the future include self-sealing concepts for coping with small suit tears or punctures, compartmentalizing of suit segments so that a tear in one segment seals off a given compartment without depressurizing the entire suit, and protective cocoons for immediately enveloping an astronaut subsequent to a sudden pressure drop. The use of an emergency pressure garment donned over the liquid cooled garment (LCG) should also be considered.
 - c. Development and application of new materials will make the suits increasingly more resistant to scuffs, abrasions, snags and tears. An amalgamation of "hard" and "soft" suit concepts may also occur to provide increased micrometeorite protection as well as general resistance to "wear and tear."

- d. Ultimately it would be desirable to design an integrated back-pack and space suit. The back-pack to be attached to the suit so that upon completion of donning the integrated pair are immediately in an operational mode. Since current hoses hang loose and are in danger of being snagged or inadvertently disconnected, a future suit would **have them integral and take up less volume than the current clumsy hoses do.** A rectangular cross section hose, flexible but not collapsible, would be a step in the correct direction.

It would be desirable to have such a suit fail-operational, fail operational, fail-safe and require a simple checkout procedure. Care should be taken that variations in turn-on or shut-off sequences for operation of such an integrated suit-backpack will not pose any dangers to the wearer. The gold, heat-reflective layer in the face mask might be emplaced between layers of plastic to ensure its protection against abrasion, peeling or scratching.

It would be advantageous to have a readout system for the oxygen flow rate so that a suit wearer would be informed on either excessive or insufficient oxygen usage as well as time-to-go in the EVA mode as a function of such flow rate.

- e. It is desirable for EVA astronauts to always use the buddy-system (ability for mutual plug-in capability - suit to suit - and use of all backpack consumables) so that feasible repairs can be made on the spot for accidental suit penetrations. A kit analogous to a tire repair kit would be desirable for such a function.

- 2. The second approach to suit damage prevention involves detailed safety attention to the design of lunar hardware systems and mission activities.

The following recommendations are made so as to improve astronaut safety:

- a. Development of shelter/vehicle ingress/egress provisions that avoid failing or snagging of suit or back-pack connections.

- b. Systematic review of all hardware surfaces that the astronaut may come in contact with to eliminate abrasive edges, unstable standing platforms (planned or unplanned) and protrusions.
- c. Design of vehicle deployment systems that preclude manual involvement of the astronaut with the possible consequence of objects falling on the astronaut.
- d. Provisions to adequately guard against lunar vehicle overturn; e.g., indications of excessive slope beyond the capability of the vehicle, roll bars and seat restraints.
- e. Development of scientific equipment hardware and emplacement procedures that precludes astronaut tripping over wires or components.
- f. Design of appropriate illumination aids for lunar night operation.

Remedial measures:

- 1. Actual use of the available suit repair kit noted in preventive measures under 1(e) is a remedial step. The buddy-system increases the feasibility of such kit use. Hazard Study 15 should be referred to for measures taken concerning vehicle overturning, equipment emplacement. Hazard Studies 7 and 22 deal with the meteoroid penetration phenomena for EVA astronauts.

Escape/Rescue Requirements for Hazard 1

Rescue options are a function of oxygen loss and a function of the distance of the disabled astronaut from a habitable shelter or source of replenishment supplies. The following provides the rescue measures or options appropriate for various conditions of suit leak rates and operational factors:

- 1. Large oxygen flow rate from suit, e.g., hose disconnected or torn.
This type of suit failure is catastrophic with state-of-the-art suits even if the astronaut is close to a lunar shelter or spare PLSS on a lunar rover. To cope with this class of suit failure new design features

are required such as automatic sealing of the hose port if the hose is disconnected as well as a method of eliminating hoses hanging loosely on the suit. The latter is discussed above in corrective measures 1(d).

2. Medium Suit Leak

This situation is defined as one in which the astronaut is losing oxygen supplies at such a rate that he has a relatively short time (say, about 1/2 hour to return to a habitable shelter.)

If a medium suit leak occurs while the astronaut is on a non-cabin rover sortie he has the following options:

- a. Ride back to shelter as quickly as possible.
- b. If ride-back distance is too far, plug into spare back-pack or vehicle-mounted life support system.
- c. Call for rescue by means of a lunar flying vehicle.
- d. If a second lunar rover is available, have it meet returning rover half way with spare back-pack.
- e. The remedial measures noted above suggesting a tire repair type kit is also recommended for the medium leak situation.

3. Small leakage

A small leak would normally allow the astronaut conducting EVA operations in the vicinity of a shelter or cabin rover to walk back to the shelter or rover. For non-cabin rover operations, the astronaut could either ride back unassisted depending on the time into the mission and the distance from the shelter or extend his life support supplies by connecting to a vehicle mounted life support reserve or a spare back-pack.

Recommendations:

1. Because the face mask is plastic and because techniques have been developed to ascertain strains brought upon plastic forms when stresses are put upon them it may be possible to adapt this technique to detecting imminent mask failure. This method depends upon the fact that the appli-

cation of force to the plastic yields a series of diffraction patterns that can be photographed. No doubt these patterns can be detected by other sensor techniques. It is recommended that studies be conducted in this area to determine the adaptability of the methodology for this use. It may be possible to have the astronaut continually wear a flexible, plastic, folded emergency cover which can be pulled over his head and sealed at the neckband as an interim measure. This technique should be studied and its value ascertained.

2. A repair kit analogous to the tire repair kit should be developed, after appropriate study, for on-the-spot remedy of small and medium suit leaks.
3. A 'clock' should be developed to inform the wearer of a PLSS how much EVA time remains for him as a function of his remaining oxygen supply and as a function of its instantaneous use rate.

Effects of Hazard 2, Back-pack Failure

The effects of the loss of use of the back-pack are catastrophic and lead to the loss of the astronaut unless sufficient countermeasures are instantly available. The effects of communications/telemetry and power failures are discussed in Hazard Studies 7 and 20 and will not be repeated here.

Primary system failure leads to switching to the emergency back-up oxygen purge system. Power failure as well as all other failures listed in the major hazard list will have the effect of (temporarily, at least) terminating the operation and require an immediate and mandatory return to a safe haven.

Corrective Measures for Hazard 2

Preventive measures:

1. A thorough and complete checkout before each EVA sortie should be mandatory for the back-pack, the suit, and all related equipment.

2. It is highly recommended that an integrated suit and back-pack be developed (as discussed in corrective measures for Hazard 1) that can be operated without concern as to the order of activation or inactivation of the hardware.

In designing such a suit-backpack all possible anticipated modes of operation must be considered so as to negate the need for any "procedural workaround" sequences resulting from deficiencies in the original equipment design.

3. The following list of items are preventive in the sense that the availability of the hardware of procedures listed will prevent loss of the astronaut if his primary system fails. In the sense that the use of the hardware and/or procedures becomes necessary the list can be considered remedial. Back-pack Failure - Reduction of the hazards associated with back-pack failure beyond the backup oxygen purge system (OPS) capability should include:

- a. A backup power system with a minimum capability of 30 minutes.
- b. A backup communications system.
- c. Mandatory use of the buddy system for all EVA except within 100 meters of the LSB.

Incorporation of "buddy system" features into back-pack design to allow an astronaut in distress to share a good back-pack with another astronaut. These features should be designed to allow for the overload imposed by two astronauts or insure that the degraded performance caused by two astronauts sharing the back-pack will not impair rescue success.

Desirability of making an emergency pack available during EVA excursions or umbilical backup supply from the base or roving vehicle as long as astronaut operations are in their proximity.

Remedial Measures:

1. Size all emergency and backup systems to all primary systems so that both survivability and rescue requirements are consistent with the rescue equipment available for the mission.
2. Emergency systems, like the primary system, should be redundant in design to provide fail-operational, fail-operational, fail-safe conditions to the overall system.
3. Use of a fellow astronaut's back-pack; that is, use of the buddy-system.
4. Availability of an extra back-pack at the operations site.

Escape/Rescue Requirements for Hazard 2

Failure of a primary backpack generally entails the same rescue/escape options as described for suit penetrations or leakages.

In these cases, the astronaut within walking distance of a shelter would return immediately to the shelter with the assistance of a companion astronaut. For the case of a non-cabin rover sortie, the lunar rover would return directly to base with the "buddy" astronaut driving the vehicle.

Recommendations:

It is recommended that studies be conducted to ascertain minimum power and communications requirements for use as backups in the event of failure of these functions in a back-pack.

Effects of Hazard 3, Back-pack Switching Accident

Should the act of back-pack switching not occur smoothly the astronaut's life support system would be lost to him and the result would be catastrophic, leading in the worst case to loss of the crew member. The effect here is the implied threat of interrupted life support functions and its consequences.

Corrective Measures for Hazard 3

Preventive measures:

1. Backpacks should be designed for "buddy system" operation. In this manner an astronaut with a defective backpack could connect himself to the backpack of his companion or his buddy could perform this function. This multiple use of a single backpack would obviously deplete remaining expendables at a much faster rate and emergency walkback capability would be accordingly reduced. In the event of vomiting this would not be done - see remedy measures below.

The buddy system is defined as that operational mode of activity wherein at least two members of a space mission crew perform tasks with both (all) members conducting tasks while near each other at the same site. The buddy system necessarily includes the capability for each crew member to use the subsystems of his fellow crew member by the existence in their equipment of hardware which permits such mutual (multiple) use.

Thus, if each of two crew members carries N subsystems (life support, communications, power, etc.) there are then $2N$ subsystems for their mutual support. The psychological comfort of having a fellow crew member immediately available in the event of accident, equipment malfunction, illness, or any other irregularity serves to greatly increase the confidence of the buddy system crew.

By no stretch of the imagination can the buddy system be considered to be in effect if one member of the team is outside a spacecraft or lunar base while his monitor(s) is inside the spacecraft or base; no matter whether the latter is suited-up or not.

2. Small cabinless lunar rovers could provide extra or spare backpacks and back-pack switching aids. Backpack switching aids conceived of to date have been cumbersome to use and far from foolproof when operated by an

unassisted astronaut. Suit/backpack interfaces have not been designed to insure an efficient and safe mating that can be managed by a single astronaut on the lunar surface. Therefore, back-pack switching requires assistance from a second astronaut or improvements in the suit/back-pack mating design and/or the aids for accomplishing this operation.

3. Small lunar rovers could be equipped with ECS provisions for either replenishing expended backpacks or for emergency plug-in for an emergency return to a lunar base.

Remedial measures:

Backpack switching in the lunar vacuum as a means for extending normal mission duration should be avoided until foolproof techniques are available and easily effected by the space suit encumbered astronaut. Emergency switching of backpacks can be effected with the assistance of a companion astronaut. In addition, backpacks should have the capability of simultaneously supporting two astronauts for emergency assistance purposes.

1. In the event of vomiting the concerned astronaut must be taken to a safe haven immediately before he chokes on his regurgitated food and before the debris clogs his suit functions. The length of time to choke on food particles trapped in the trachea is a function of the percentage of obscuration of the air passage. For total blockage the time is about 2 minutes - about the time a good diver can hold his breath under water.

Recommendations:

It is recommended that a study be made to determine techniques of opening an astronaut's faceplate to help him clear his suit of regurgitated debris and to aid in clearing his mouth and throat of this debris. A totally enclosing, inflatable, zipper closed 'balloon' is a possible approach to this problem.

DATA SOURCES

1. "Apollo Portable Life Support and Oxygen Purge System" Hamilton Standard Booklet B-231, Undated.
2. "Advanced Extra Vehicular Protective System for NASA Ames Research Center," Quarterly Progress Report, Contract NAS 2-6021 - Hamilton Standard July 1 through Sept. 30, 1970.
3. "Comparative Analysis of Life Support Systems for Emergency Return During Lunar EVA - Case 320," TIA. Bottomley, 19 December 1969.
4. "Synopsis of Safety Considerations for Lunar Surface Vehicles," General Electric Co. Report SS-TR-060-3, 25 June 1970.
5. "AESS Space Suit Requirements," Garrett AiResearch Manufacturing Co., Undated.
6. "A7L-B Suit Data for Design of Lunar Roving Vehicles (LRV)," NASA Supplied Data, dated Feb. 2, 1970.

HAZARD STUDY 23
SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. Back-pack switching in the lunar vacuum environment shall not be required as a means for normal extension of mission duration.
2. Back-pack switching aids shall be provided only for emergency-switching of backpacks.
3. Back-pack design shall permit buddy system attachment and operation for all life support functions and power and communications.
4. Emergency life support shall be provided in the form of spare back-backs, vehicle mounted systems or strategically located supply caches distributed along a mission route. Specific requirements shall be mission peculiar.
5. The "buddy system" using astronauts at least in pairs for all EVA operations, or the presence of a safety man, should be mandatory.
6. Space suit design efforts should continue to stress increased astronaut mobility performance capabilities, integrations of separate suit elements into one garment, increased resistance to tear and abrasion and emergency corrective measures to prevent catastrophic suit leaks.
7. Lunar hardware systems must be designed to preclude accidental damage to suits and backpacks. Such measures include development of safe vehicle/shelter ingress/egress provisions and aids, avoidance of abrasive hardware edges and protrusions which can snag suits or hoses.
8. Scientific mission activities shall be organized to avoid tripping over emplaced scientific equipment and its connecting cables.
9. Repair kits, analogous to the tire repair kit, should be available for all EVA astronauts (in general, for all suited astronauts) in order to be able to repair minor and medium suit leaks.
10. All back-packs and interrelated equipment should be designed to fail-operational, fail-operational, fail-safe.
11. All hose connections should have automatic, self-sealing ports for the eventuality of inadvertent hose-disconnection.

12. External protuberances such as hoses, electrical lines, etc., on all space suits should be eliminated by improved design.
13. The gold plated, heat reflective layer on the spacesuit face masks should be sealed between two layers of plastic in order to protect that layer from scratching, abrasion, or peeling.

HAZARD STUDY 24

LUNAR FLYING VEHICLE HAZARDS

INTRODUCTION

A lunar flyer may be used for the scientific investigation of areas of the Moon that would be impossible to reach with surface transportation. Such areas as crater walls and ridges, central crater peaks, the uppermost promontories and cliff faces may involve the use of the flyers. The flyers considered here are the non-cabin type, with life support and communication provided by personal life support systems (PLSSs). They can carry at least two men.

ASSUMPTIONS

1. The lunar flyer preferred crew is two or more, but a flying investigation could be conducted by one man.
2. The flyer will have a limited range capability which is considered to be about 13 km (8 nm).
3. Sites selected for lunar flyer investigations will in general have been photographed from orbit and perhaps from the lunar surface in order to obtain topographical knowledge for the scientific investigations and to permit planning for escape/rescue should that become necessary.

THE MAJOR HAZARDS

The major hazards identified are:

1. A lunar flying vehicle impacts the surface at excessive velocity following malfunction of a critical subsystem or through control input error.
2. Loss of communications.
3. A PLSS malfunction during the course of a lunar flying mission.

4. Poor visibility of the lunar surface during landing, considering lunar dust and sun-lighting effects.

ANALYSIS OF IDENTIFIED HAZARDS

Effects of Hazard 1, Excessive Impact Velocity

A high velocity impact will result in the loss of the lunar flyer crew. Other crew members of the lunar complex would investigate the accident but not in a rescue mode if the impact at high velocity was 'seen' on radar or by other means.

Should the lunar flyer and crew experience a low velocity impact the expectation is that the crew will suffer some injury and the flyer will be damaged so that it would at least be in need of repair before it could be used again. A major concern involves the sudden isolation of the crew in the event of an impact. If astronaut injuries are of a serious nature the isolation problem is compounded. Should the crew's PLSSs be damaged the severity of the problem increases further.

Corrective Measures for Hazard 1

Preventive Measures:

1. Duplicate the propulsion and control systems, except for tankage and propellant, so that either system is capable of operating the flyer. Fail-operational, fail-operational, fail-safe philosophy should be observed.
2. Limit the altitude and velocity of the lunar flyer so that the highest impact speed or fall from highest operating altitude will not likely result in serious injury to the crew.

3. Special protection for the PLSS should be designed for use with the lunar flyers to prevent loss of integrity in the event of low velocity impact. In addition, an emergency oxygen supply, capable of withstanding the impact without impairing its function, should be available for each crew member.
4. A crash-survivable communications beacon and voice transmitter should be aboard every flyer.
5. To further limit isolation the use of a preferred mode of lunar flyer operation is suggested. This involves towing the flyer on a trailer attached to a rover (preferably cabin type) to near the site of interest. The lunar flyer is then used to get to the desired site. A total rover-flyer crew of three is suggested as a minimum for this operation.

Remedial measures:

1. If injuries and PLSS damage are such that the crew members are ambulatory and life support available, rescue assistance should be requested from the surface operations base. The flyer crew could then walk on a prescribed path to meet the rescuers. This situation implies that the duration of the impact site can be negotiated by the crew on foot.
2. Alternately the crew would have to make use of their first aid equipment and communications capability until outside aid was available.

Escape/Rescue Requirements for Hazard 1

1. If the crew is ambulatory after their accident they would contact their operations center and proceed on foot on a prescribed path maintaining radio contact throughout while a rescue party got underway.
2. If injuries are too severe to permit movement, the crew members would have to be rescued within the time limits bounded by PLSS supplies.

Effects of Hazard 2, Communications Loss

This hazard is discussed in Hazard Study 29 and will not be repeated here.

Effects of Hazard 3, PLSS Malfunction During a Lunar Flyer Mission

This hazard is dealt with in detail in Hazard Study 23 and will not be repeated here.

DATA SOURCE REFERENCES

1. NASA-MSD Surface Transportation PDD, June 1970
2. One-Man LFV, SD69-419-1, Final Report
3. One-Man LFV, 7335-950012, Summary Report
4. Lunar Escape Systems, SD69-598, Tech Report, NAS Space Division, Oct 1969
5. Lunar Escape Systems Summary, NAS CR-1619
6. Manned Lunar Flying Machines, Meyer/Kitchens, paper to SAE, May 1968
7. Lunar Flying Vehicles, 7266-950001, Bell Aerosystems, January 1967
8. Apollo12 Mission Report, MSC-01855, March 1970

HAZARD STUDY 24
SUMMARY OF SAFETY GUIDELINES

1. Lunar flying vehicles shall have fully redundant propulsion and control systems, except for propulsion tankage and propellant. Fail-operational, fail-operational, fail-safe philosophy shall be observed.
2. Each lunar flyer vehicle shall carry a communications beacon and voice transmitter capable of withstanding any crash survivable by a crewman.
3. Special protection from low velocity impacts should be provided for EVA backpacks used on lunar flyer missions, and an additional emergency oxygen supply capable of withstanding the impact without impairing its function should also be provided.
4. Lunar flyers shall be prohibited from landing in any area which cannot accommodate a second flyer.
5. All solo lunar flyer missions shall have a crew of at least 2 men with the vehicle flyable by one man.
6. All lunar flyers shall be capable of carrying at least one pilot, plus one passenger who may be incapacitated.
7. Use of two flying vehicles on each flyer mission, each capable of returning the crewmen of both vehicles, is strongly recommended.
8. Continuous communication with the base is required for the entire period of all lunar flyer missions.
9. In planning flying missions into potentially dangerous locations a rescue plan shall always be determined beforehand. The range/time capability of the rescue mode shall determine the maximum allowable range/time-away-from-base of any lunar flyer mission.
10. Mission planners must have a precise knowledge of the limitations in performance of the flyer/crewman combination and detailed information on landing site topography prior to initiating a lunar flyer mission.

11. Lunar flyers shall be operated only when solar lighting conditions will be favorable for both the outbound and inbound legs of a mission, except in an emergency.
12. Immediately after landing a lunar flyer at a remote site the crew shall determine the status of their vehicle and report findings to to the base.

HAZARD STUDY 25 TOTAL DESTRUCTION OF A PRIME VEHICLE

INTRODUCTION

This study area considers the hazards generated as a consequence of the total loss of any one of the prime program equipment elements. These prime elements include transport vehicles, lunar lander tugs, orbiting lunar stations, lunar surface bases, roving vehicles, and flying vehicles.

ASSUMPTIONS

1. The total loss of a program element is assumed to occur suddenly and without prior warning. Causative factors are not considered a part of this study.
2. Nominal mission activities are assumed to be in progress at the time of the loss event.

THE MAJOR HAZARDS

The hazard generators are considered to be:

- a. Loss of a chemical or nuclear prime transport vehicle (PTV)
- b. Loss of an orbiting lunar station (OLS)
- c. Loss of a lunar lander tug (LLT)
- d. Loss of a lunar surface base (LSB)
- e. Loss of a lunar roving vehicle (LRV)
- f. Loss of a lunar flying vehicle (LFV)

The loss of one of these prime equipment elements is considered to generate the following hazards.

1. Vehicle debris, and perhaps contaminating particles, are left in lunar orbit or on the lunar surface following destruction of a program element.

2. Crewmen are stranded and/or deprived of metabolic needs and a safe haven following destruction of a prime vehicle or base.
3. Hazardous survivor search, extraction, and recovery is required following destruction of a program element.
4. Rescue capability is lost following destruction of a program element.

ANALYSIS OF IDENTIFIED HAZARDS

Effects of Hazard 1, Vehicle Debris

Vehicle debris or contaminating particles left in lunar orbit or on the lunar surface, following destruction of a program element, constitute a collision hazard and perhaps a nuclear radiation hazard. These hazards may be present for long periods unless action is taken to eliminate them.

Corrective Measures for Hazard 1

Preventive measures:

None identified.

Remedial measures:

1. Manned or unmanned space tugs might be used to capture and dispose of non-radioactive debris in orbit, through deorbiting to a safe area on the lunar surface, boost to escape velocity, or hold for return to Earth.
2. Unmanned space tugs might be used to capture and dispose of radiation-contaminated debris in orbit through boost to escape velocity.
3. Impact of radiation-contaminated materials on the lunar surface may require quarantine of a considerable surface area until the specific debris location can be identified and either cleaned up or enclosed.

Escape/Rescue Requirements for Hazard 1

None identified.

Effects of Hazard 2, Stranded Crewmen

Destruction of a prime vehicle may create hazards of isolation or deprivation of life support needs for crewmen dependent on that vehicle, but spared from the initial destructive event. These situations may include:

- a. Crewmen are in a tug in lunar orbit when their orbiting lunar station is destroyed.
- b. Crewmen are in an orbiting lunar station when their stand-by tug is destroyed.
- c. Crewmen are in a lunar surface base when their stand-by tug is destroyed.
- d. Crewmen are on surface EVA from a solo lunar lander tug when that tug is destroyed.
- e. Crewmen are on EVA from a roving or flying vehicle traverse when their rover or flyer is destroyed.
- f. Crewmen are on local EVA when their lunar surface base is destroyed.
- g. Crewmen are in an orbiting lunar station awaiting resupply and crew rotation when the incoming prime transport vehicle is destroyed.

The effects of these situations may range widely, from imposing a need to wait in relative comfort for rescue or delivery of a replacement tug (situations b and c) to urgent need for additional life support and rescue (situations d and e). A very sizeable study would be required in order to consider the full matrix of situations, conditions, and hazard effects possible following loss of prime program elements. This cannot be accomplished here, and the following corrective measures are therefore of a very general nature.

Corrective Measures for Hazard 2

No preventive measures are identified.

Remedial measures:

1. Provide a rescue capability and rescue plan which considers all credible combinations of loss of a prime element with mission phase, mission timing, and crew activity.

Escape/Rescue Requirements for Hazard 2

See remedial measures statement above.

Hazards 3 and 4 are beyond the scope of this study, but will require careful attention in detailed future mission planning.

RECOMMENDATIONS FOR FURTHER STUDY

Much of the analysis required to properly analyze and cope with the hazards identified here is beyond the scope of the present effort. It is nonetheless evident that loss of a program element could have serious consequences that must be considered in planning for advanced lunar operations. The following studies are therefore suggested:

1. In the planning of future missions a study is required to determine the credibility of total loss, individually, of each prime item of lunar exploration equipment proposed.
2. It is recommended that a position study be accomplished relative to the disposition of non-nuclear vehicle debris which may be generated in lunar orbit.
3. It is recommended that a joint NASA/AEC position study be accomplished relative to the disposition of nuclear debris which may be generated through accident or failure in lunar orbit.

HAZARD STUDY 25
SUMMARY OF SAFETY GUIDELINE CANDIDATES

1. Prior to the initiation of advanced lunar missions, methods and a plan shall be devised for disposing of nuclear and non-nuclear debris in lunar orbit. Use of a space tug in both manned and unmanned configurations shall be considered for use in debris removal.
2. Prior to the initiation of advanced lunar missions a rescue plan which considers all credible combinations of loss of a prime element with mission phase, mission timing, and crew activity, shall be developed.

HAZARD STUDY 26

THE HAZARD IN LUNAR ROVER OPERATION CREATED BY LIGHTING CONDITIONS
AND GEOMETRY ON THE LUNAR SURFACE

INTRODUCTION

After the initial lunar base has been firmly established, well stocked, and is in the expected operating mode, explorations of the surrounding lunar surface will commence. Lunar rovers of various types will be used to support this exploration with distances from the base growing as capability and confidence of the lunar base crew increases.

The explorer's ability to see on the lunar surface is strongly modified by the Sun elevation angle and by the azimuthal direction of travel for a given Sun elevation angle. The loss of "landmarks" (i.e., shadows vanish) due to increased elevation angle is well demonstrated by the simulation studies - and resultant photography - in Ref. (a). Lunar illumination at high Sun elevation angles (viz., above 17° for fairly flat lunar surface) is harsh, glaring, and wipes out all shadows thoroughly. Unless preparation is made during the course of each early sortie, so that a network of artificial landmarks are emplaced, difficulties in navigation will ensue leading to serious accidents and/or death of the rover crew.

ASSUMPTIONS

1. Exploration of the lunar surface will lead to lunar rover sorties at increasing distances from the lunar base. The open rover at distances up to 8 nm (13 km), the cabin rover at distances measured in hundreds of kilometers. Both of these extended types of sorties are evidently beyond walkback capability for astronauts.
2. Exploration distances will increase to the extent that the full range of lunar surface lighting conditions will be encountered on many - and eventually almost all - lunar rover trips. This

excludes local travel to newly landed tugs, etc., in the immediate vicinity of the lunar base.

3. Crevasses and weak-roofed "holes" exist in various parts of the, as yet, unexplored lunar surface.
4. Location of all crevasses and "holes" will not be known for many decades, if ever.

THE MAJOR HAZARDS

The major hazards identified are:

1. Failure to see a crevasse because of poor lighting conditions with subsequent entrapment of the rover and crew.
2. Inability to navigate because natural landmarks are unseeable in poor lighting caused by high sun elevation angles - above 17° from either the eastern or western lunar horizons.

ANALYSIS OF IDENTIFIED HAZARDS

Because the two hazards are so interrelated they will be treated simultaneously in the analysis.

Entrapment of the rover and its crew in a crevasse could occur far enough from the lunar base so that walking back to the base is out of the question. Entrapment could have occurred because rover motion during poor lighting conditions obviated seeing the crevasse beforehand. The Sun elevation angle is assumed to be greater than 17 degrees for this event.

Effects of Hazards 1 and 2

Loss of entire crew if not rescued. Oxygen will run out.

Corrective Measures

Preventive measures:

1. Develop method for locating, marking crevasses' locations.
2. Information presently is insufficient for preventing rover entrapment by weak roof cave-in except by 'hole' detector. This would severely limit rover rate of travel on lunar surface unless an unmanned device preceded the manner rover over the path.
3. Navigate via stars, if visible. Emplace lunar surface buoys during good seeing conditions. Buoy design must be independent of lighting conditions on lunar surface.

Escape/Rescue Requirements

Escape/Rescue requirements cannot be presently established for this case because of lack of information and data on lunar surface lighting conditions.

RECOMMENDATIONS

The following recommendations are made to alleviate this lack of knowledge noted above.

1. In general, not enough is known about navigation during high-Sun-elevation-angle-derived, poor lunar surface lighting conditions. Remaining Apollo lunar missions should incorporate experiments to collect data on lunar surface lighting and seeing conditions as functions of:
 - a. Sun elevation angle independent of azimuth of travel.
 - b. Sun elevation angle for various fixed azimuth angles.
 - c. Gross roughness of the lunar surface.

2. Crevasse detection techniques must be developed as well as methods for detecting 'weak-roofed holes' - if they exist. Suggest experiment for Apollo rover lunar missions.
3. Navigation methods should be developed to circumvent poor lighting conditions and permit seeing of obstacles in any lighting geometry. Use should be initiated on Apollo-rover lunar missions. Presently navigation without visual contact with the lunar surface - or using video - does not seem to be possible allowing, however, for one special type of case. In the latter, the rover crew has laid out lunar buoys (beacons) along its path while moving away from the base in a manner such that the straight line path between two consecutive beacons has no obstacles of consequence to the passage of the rover. With each beacon coded so as to present a unique path and set of directions for the rover, the crew could return along this path without any external visual contact. This method might be termed a homing technique for navigation.

Velocity techniques for navigation which include computing range, range to go, and position coordinates, or inertial or celestial methods are all equally useless navigation techniques since they do not account for obstacles in the rover traverse pathway.

DATA SOURCE REFERENCES

1. Apollo Illumination Environment Simulation and Study, Vol. II, W. K. Kincaid, Jr., S. Seidenstein, J. A. Janousek, NAS 9-7661; Biotechnology Organization, LMSC, for NASA/MSC.

HAZARD STUDY 26
SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. A device, analogous to mine detectors, must be designed in order to determine hidden crevasses and roofed holes on the lunar surface. This device, if needed, should be attached to the front of all lunar rovers on a long enough extension (truss) so that the rover may be stopped in time, at its highest speed, if such a hazard is detected.
2. Navigation techniques must be developed for use on the lunar surface with lunar rovers, and with lunar flyers, which are independent of any and all lighting conditions on the surface.
3. As aids to navigation on the lunar surface, 'buoys' should be developed containing coded radio beacons and flashing lights, and powered by radio-isotope power sources of at least five years' lifetime. Radio beacons should be detectable at a distance of at least 50 miles using omni antennas on the lunar rovers.

HAZARD STUDY 27
VISIBILITY CONSIDERATIONS IN DOCKING TWO VEHICLES (SPACECRAFT)
IN LUNAR ORBIT

INTRODUCTION

During the course of prior activity in the Apollo program and Space Shuttle studies the phenomena of lighting/visibility in Earth orbit was recognized as an area for investigation as reflected in docking procedures. Because of the lack of light-scattering dust and atmosphere and because of lack of penumbra in shadowing, spacecraft are either in complete darkness or are illuminated by bright sunlight. Reflections from spacecraft surfaces are harsh and blinding.

Visibility for docking is based on three factors:

1. The geometry relating target spacecraft, docking spacecraft, the Sun and the Moon determines the illumination of objects within the field of view of the docking crew.
2. The nature of the spacecraft surfaces and shapes which reflect the ambient illumination incident on those spacecraft. This determines contrasts within the field of view, particularly glare highlights and obscuration by shadow.
3. Window position and field of view size and shape which interface with the first two factors and determine "Sun-shafting" through the window-viewports and scene veiling effects caused by scatter within the window media.

Visibility considerations may constrain docking port location and orientation and can effect the design requirements for the docking port area and its associated mechanisms.

ASSUMPTIONS

- a. Docking between any two spacecraft, in normal circumstances, can occur with:
 - 1) Both roll axes parallel and coincident.
 - 2) The roll axis of the active spacecraft is perpendicular to the roll axis of the orbiting lunar station.
- b. During routine operations the solar arrays of the orbiting lunar station are normal to the Sun's rays and the station roll axis is parallel to the Sun's rays.
- c. Docking is normally accomplished in daylight.
- d. Docking is performed with the station in a zero-g flight mode.
- e. External station surfaces highly reflective (say $\geq 50\%$), solar arrays 20% reflective.
- f. Sky or dark lunar surface background with docking port illuminated by the Sun and some lunar reflection, or by the Sun only.
- g. Prior analysis for the shuttle docking-lighting geometry is used here while observing that the lunar spacecraft shapes will lead to different but closely related results.

THE MAJOR HAZARDS

The Major hazards identified are:

1. Docking attempts in daylight with spacecraft-Sun geometry not proper leads to multiple docking attempts, possible minor collisions.
2. Side docking attempts with incorrect lighting relationships could lead to collision with solar arrays. This, in turn, would deny some or all solar-array generated electrical power to the orbiting lunar station.

ANALYSIS OF IDENTIFIED HAZARDS

Effects of Hazards Nos. 1 and 2, Docking attempts with incorrect lighting geometry

Solar 1 Orientation:

The hazard of collision exists because of attempts to dock when lighting geometry leads to poor seeing conditions. During the course of contractual studies for NASA, lighting geometry was examined for Apollo docking and for the Launch and Reentry Vehicle (Shuttle to Space Station) docking procedures, Ref. 1, 2. A current study to examine docking/lighting geometry for the Skylab program is also underway (Ref. 3).

The results of these initial studies define a Sun angle, viz., the angle bounded by the docking (roll) axis of the active spacecraft and the incidence line of the Sun's rays (see Figure 1); the positive angle being measured from the establish + X axis. It is assumed here that the roll angle for each vehicle is fixed with respect to the Sun line.

Results of these studies - conducted as simulations using scale models - indicate that for Sun angles of less than 60 degrees, Sun shafting through the docking viewport or Sun incidence causing veiling (light scatter due to the viewport media) occur in present spacecraft. For Sun angles greater than 140 degrees, obscuration of the orbiting lunar station docking target and port by the shadow of the active spacecraft (e.g., a logistic tug) will occur.

The effects of the simplification calling for a constant Sun angle for all spacecraft angles (roll angle with respect to Sun line) have not been examined to date in the contractual simulation activities. Consequently, the effects of varying the spacecraft angle on lighting geometry are presently unknown.

End-Port Docking with Orbiting Lunar Station in Normal Sun Orientation:

Since the light geometry is very poor for end-port docking under normal Sun orientation - it is either too dark or too bright - any attempt to dock

under these poor seeing conditions will lead to either collision or multiple and therefore fatiguing attempts to dock (viz., Apollo 9 McDivitt/Schweikhart in LM, multiple tries to dock in bright sunlight with D. Scott in CSM). Fatigue again presents the hazard of collision.

Viewport filters or sunglasses do not aid the docking visibility because many of the (visibility) problems are derived from the extreme brightness variations present in the visual scene. The eye adapts to the average brightness value of the visual field resulting in lack of visibility in the extreme (darkness or bright glare). Attenuation of light to the eye reduces the glare extreme, but results in proportionately reduced visibility at the dark extreme by reducing the energy reaching the eye to below its absolute sensitivity threshold. Docking lights have no significant effect within the feasible energy ranges (for such lights) because the amount by which they raise the luminous reflection from the dark areas is not sensed by the eye because the eye is adapted to a much higher brightness band in this situation.

If the space station cannot be reoriented during docking, the dark-end docking port is unacceptable on the daylight side of the orbit while the Sun-end port is unacceptable because the Sun angle is 180 degrees. Both of these cases are outside of the Sun angle envelope; both give bad seeing conditions, the former literally leaves the pilot in the dark while the latter not only places the pilot in the glare due to reflection of Sun-light from station surfaces, but also may expose him to the glare envelope resulting from highly specular solar array cells.

Corrective Measures for Hazards 1 and 2

Preventive measures:

1. Reorient the orbiting lunar station as necessary during docking to yield acceptable Sun angles.

2. Limit docking at end ports to the dark side of the orbit, and use floodlights for illumination, since here the eyes can become fully dark adapted and the range of brightness in the visual scene is substantially reduced.
3. Dock only at the side ports (90 degree Sun angle is fully acceptable) when on the daylight side of the orbit.
4. A design alternative would be to have the end docking port - on the dark end of the station - angled at 45 degrees to the station center line. This yields a 135 degree Sun angle which is acceptable on the daylight side of the orbit.

Escape/Rescue Requirements for Hazards 1 and 2

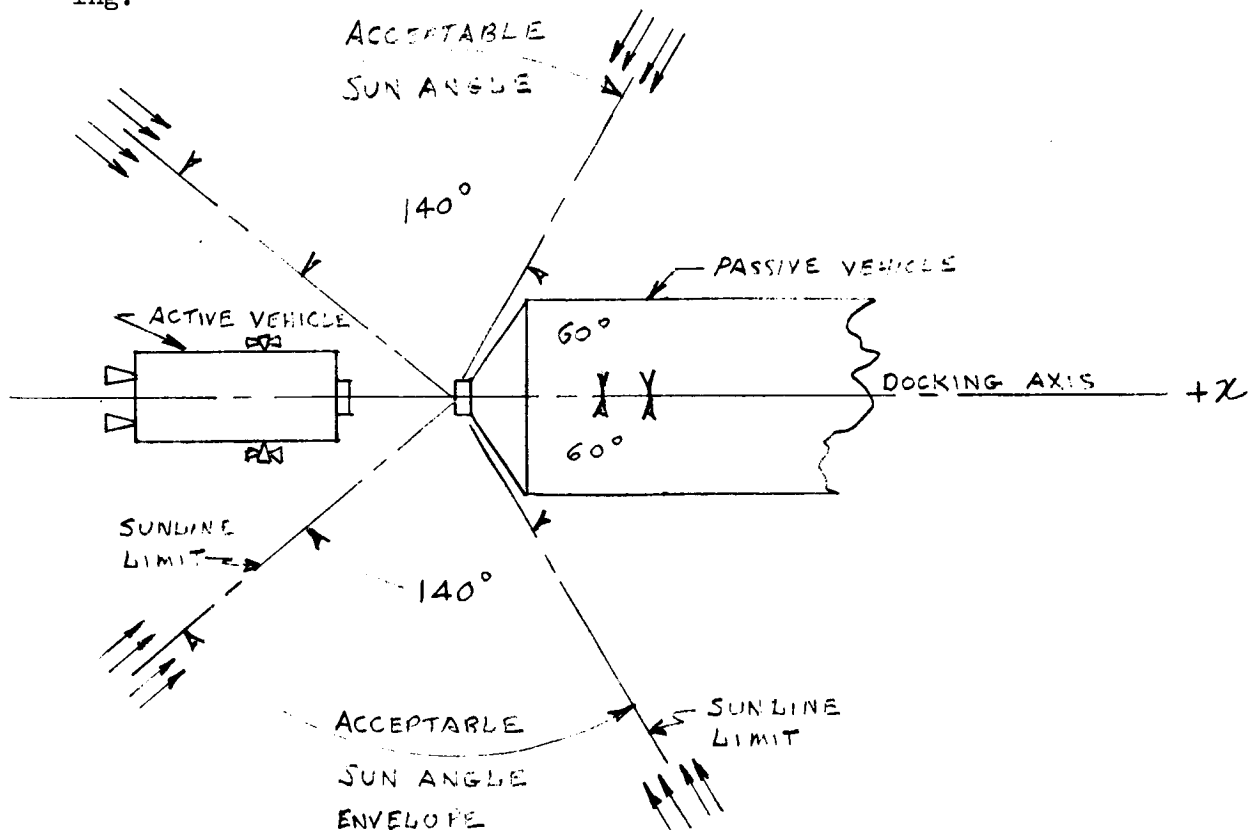
No escape/rescue requirement exists for this hazard.

DATA SOURCES REFERENCES

1. Apollo Illumination Environment Simulation and Study, W. K. Kincaid, Jr., and L. M. Glasser, Biotechnology Organization, LMSC, NAS 9-7661, for NASA/MSFC.
2. Integral Launch and Reentry Vehicle, NAS 9-9206, LMSC-A959837, dated 22 September 1969, for NASA/MSFC.
3. Solar Illumination Environment Simulation (currently in progress at LMSC, Biotechnology Organization) NAS 9-11237, for NASA/MSFC. Subject of this study is Skylab docking.

HAZARD STUDY 27
SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. During daylight docking with an orbiting vehicle, the Sun line should be maintained within the limits shown on the accompanying sketch (Fig. 1). Specific geometry may narrow these limits in order to avoid glare or veiling.
2. Problems of Sun orientation during docking may be avoided by completing the maneuver on the dark side of the orbit while using artificial lighting.



NOTE: The limits shown were obtained from lighting simulation studies at Lockheed Missiles & Space Company under contract to NASA.

Fig. 1. Definition of Docking Sun Angle for a Space Shuttle/Space Station Configuration

HAZARD STUDY 28
LIGHTING AND VISIBILITY DURING LANDING
(WITH LUNAR DUST EFFECTS)

INTRODUCTION

The dust layer on the surface of the Moon varies widely during LM landings based on the limited evidence from the three landings that have occurred to date. Armstrong's remarks just before touchdown to the effect that....'we are raising a little dust here,' and Conrad's remarks about great obscuration while still several tens of feet above the surface serve to support that early conclusion (Ref. 1, 2)

The discussion in Ref 3 indicates that a veiling luminance can exist, due to sunlight striking the dust plume formed during landing, between the lunar surface and the viewer inside the LM. The sun also illuminates the lunar surface beneath the dust plume but such illumination is strongly attenuated by the dust plume leading to a decreased surface luminance. As the LM descends to a point close to touchdown the shadow of the LM and light transmission loss due to the dust plume yield poor viewing conditions. At a height from five feet above the surface down to two feet the lighting conditions deteriorate very rapidly until at two feet the surface is badly obscured.

In addition to problems raised by sun illumination of the lunar surface at undesirable sun angles, there may be situations in which no sun illumination exists at all, that is, a night landing. The latter requires floodlights on the tug for use during landing. The optimum location of such floodlights is a tug design problem.

The hazard of poor visibility when very close to the surface really focuses on whether or not a lunar rock (or deep hole) exists, where any of the footpads touch down, which will be sufficient in height (or depth) to cause the spacecraft to overturn or land at an angle precarious for lift-off procedures

later on. It is assumed that sufficient information exists beforehand to preclude any landing on so steep an incline that the tug will topple over upon landing.

ASSUMPTIONS

1. The dust layer conditions at any new landing site on the lunar surface will be essentially unknown.
2. Eventually, at the 'permanent' lunar base a prepared landing site will be available so that little or no dust will be raised on landing at the base.
3. At the time that space tug landings commence on the lunar surface the lunar vertical indicators carried aboard the tug will be accurate to a small fraction of a degree. It is assumed that two such instruments are aboard, each independent of the other, and that tug pilots will believe their instruments.
4. Whenever there are more than two crew members making a descent at least one of the crew will be assigned as an observer to aid the pilot during the last one hundred feet or so and to search for surface hazards.
5. Given the choice, landings will occur under preferred sun lighting conditions. However, because of the possibility of rescue operations occurring at any time, landing capabilities must be independent of sun lighting conditions.

MAJOR HAZARDS

1. During the last few feet of the landing procedure the thruster(s) plume impinges on the lunar surface. This leads to visual obscuration of the landing site by virtue of the copious quantity of dust raised. The apparent (visual) landing geometry is therein distorted which may lead the pilot to set an incorrect attitude into the spacecraft resulting in the potential hazard of overturning on landing.

ANALYSIS OF IDENTIFIED HAZARDS

Effects of Hazard 1, Visual Obscuration by Dust

The discussion in Ref. 1 includes a description of visual obscuration due to dust during the landings on the Apollo 11 and Apollo 12 Lunar Modules. Conrad's landing appeared to be precarious because he had great difficulty in seeing the lunar surface during the last 50 feet (approximately) of descent. (Ref. 2) He also stated that he had considerable doubt about his lunar vertical indicator's reading during that final landing interval, which suggests poor visual information since the indicator proved to be correct. The visual problem is a function not only of the dust cloud raised per se but also of sun lighting/elevation angle effects and spacecraft orientation with respect to the sun's rays.

If the spacecraft touches down at incorrect attitude or velocity, it may overturn or be damaged. Some of the crew may be injured. A lander footpad touching down on a large rock could also cause overturning or a precarious attitude for liftoff.

Corrective Measures for Hazard 1

Preventive measures:

1. Visual conditions are improved by conducting landings at relatively low sun angles with surface features in high contrast. A landing approach with the sun at the pilot's back should also be selected if possible.
2. Great reliability should be built into the lunar vertical measurement and indicator system such that the pilots can have faith in the information displayed and have less need to depend on clear visual information.
3. Since most tug landings will be conducted with more than two crew members on board, it should be advantageous to have one or more members acting as observers from the time the tug reaches 100 feet (approx.) altitude until touchdown. Essential 'landing adjustments' to avoid obstacles can be made

by the pilot as a result of receiving information from his observers.

Remedial measures:

1. Measures to correct damage resulting from a bad landing charged to visibility will be no different from corrections for landing damage resulting from other causes. Some means for leveling a tilted lander should be provided. This may be accomplished by using jacks built into the landing legs or carried as auxiliary equipment aboard the tug. Rescue assistance may be required if the vehicle cannot be safely flown back to lunar orbit.

Escape/Rescue Requirements for Hazard 1

If, despite full attention to corrective measures noted above, the tug overturns or is rendered inoperative on landing then the crew must be rescued. Some members may be injured.

Effects of Hazard 2, Landing at a Precarious Attitude

The spacecraft can set down in a deep hole or on a large lunar rock even with good visual observation of the landing site. The LM in the Apollo 14 flight did set down with one leg in a shallow crater; the situation was not identified until the astronauts came out for their first EVA, (Ref. 4).

With or without good visibility, 'roofed' holes or a crevasse obscured by loose lunar surface material are hazards not discernible by visual observation. As a consequence, some other detection technique will have to be developed if this phenomena presents itself. The roofed hole and covered crevasse is fairly common in Antarctica where much equipment and several lives have been lost in encounters with these hazards. The effects of this hazard are similar to Hazard 1 in that the spacecraft may overturn or be damaged as one footpad settles in a roofed hole or covered crevasse; some crew members may be injured. The spacecraft may be left in an undesirable attitude for liftoff.

Corrective Measures for Hazard 2

Preventive measures:

1. Methods for detecting and avoiding 'roofed' holes or local surface areas with low bearing pressure capability may need to be developed.
2. It is recommended that dynamics studies of landing be performed in order to determine whether an abort or hovering maneuver can be automatically programmed to occur at any time the lander tilt attitude exceeds a pre-selected safe angle.

Remedial measure for Hazard 2 are identical to those for Hazard 1.

Escape/Rescue Requirements for Hazard 2

If, despite full attention to corrective measures noted above, the tug overturns or is rendered inoperative on landing then the crew must be rescued. Some members may be injured.

Effects of Hazard 3, Night Landing Accident

Because the actual occurrence of rescue situations cannot be predicted, and because any given rescue operation may take place independent of prevailing lighting conditions, the tug and its crew must be prepared to make night landings. When landing at night the tug crew will be dependent upon their instruments and artificial lights for guidance. Error may result in damage, overturn, or disabling of the tug on the surface and crewmen could be injured.

Corrective Measures for Hazard 3

Preventive Measures:

1. Multiple flares used for night landings could be fixed so as to cast light on the landing area while the tug is still hovering and preferably used for several minutes before hovering itself ensues.

2. Floodlights should be mounted on the tug and oriented to provide optimal lighting of the lunar surface.
3. It is suggested that portable lighting equipment be provided on all tugs so that the crew of a disabled tug on the surface - some of whose members are presumably uninjured - can lay out lights in a safe landing area.

Remedial measures for Hazard 3 are the same as for Hazard 1.

Escape/Rescue Requirements for Hazard 3

If the tug makes a faulty night landing which disables the tug, then its crew in turn will have to be rescued.

DATA SOURCE REFERENCES

1. Log of Apollo 11, NASA EP-72, Page 4, "4:05 PM (EDT) ... picking up some..." Aldrin/Armstrong at 30 ft. altitude at Tranquility Base).
2. Aviation Week & Space Technology, November 24, 1969, Page 22, "...lot dustier then..." (Conrad commenting on dust in Oceanus Procellarum; altitude - 50 ft.)
3. LM Soil Erosion and Visibility Investigations, Part 1, Summary Report, R. E. Hutton, 11176-606-RO-00, TRW for NAS/MSC, August 13, 1969.
4. Communications via CBS from Astronauts Shepard and Mitchell at beginning of EVA 1 during Apollo 14 mission.

HAZARD STUDY 28
SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. Provision shall be made in the design and planned operations of manned lunar lander vehicles to have crew members acting as observers commencing at 100 ft altitude to advise the pilot of surface conditions and obstacles.
2. Routine lunar landings shall be planned with a preference for times of low angle sun lighting. In particular, landings at unexplored sites during lunar night, or times of high angle sun lighting, should be avoided except for emergencies.
3. Methods for detecting and avoiding 'roofed' holes, or local surface areas with low bearing pressure, during lunar landing shall be developed, unless it can be shown that such hazards do not exist.
4. Rescue landers shall be provided with flares and floodlights for use during night landings.
5. Surface crews shall be provided with lighting equipment, signal devices, and radio beacons, as well as voice communication equipment for assisting a manned landing at their surface site.
6. Surface crews shall aid incoming landers by site preparation and/or selection, identification of obstacles, lighting, and steering information where possible.
7. The dynamics of landing should be studied to determine whether an abort or hovering maneuver can be automatically programmed to occur at any time the lander tilt attitude exceeds some preselected safe angle.
8. Means for leveling vehicles following landing on the lunar surface shall be provided.

9. The use of various optical filters in lander viewing ports should be tested in an effort to find means for reducing the effects of glare on vision.

HAZARD STUDY 29
COMMUNICATIONS ON THE LUNAR SURFACE

INTRODUCTION

During the course of lunar surface exploration various activities will occur outside of the base itself (i.e., out on the lunar surface). Lunar surface operations will involve landings from and departure to lunar orbit, operations in small and large bases, surface EVA either in the base vicinity or from a rover or lunar flyer out on a traverse. The success of all of these operations is a strong function of the ability to maintain good communications among all the elements of the system including those on the lunar surface, in lunar orbit and at the Earth.

The communications system will provide the following functions:

1. Navigation aid and position reporting
2. Status monitoring of all elements
3. Data/Information flow
4. Engineering aid requests for experiments, vehicles, etc.
5. Provides assurance of safety and well being for the crews.

ASSUMPTIONS

For small bases (e.g., Lunar Lander Tug)

- a. One or more men will be inside the base at all times.
- b. One or more men may participate in activity within 1 nm (less than 2 km) of the landed tug in an EVA mode.
- c. Two or more men may be out in a small rover or lunar flyer a distance of up to 8 nm (13 km) from the base.

For the extended lunar surface base, similar conditions will hold along with the increased capability of this larger base:

- d. One or more men will be inside the base at all times, except in emergency situations.
- e. One or more men may participate in activity in the immediate vicinity of the lunar base; they may not be further away than one nautical mile (less than 2 km) from the base at any time.
- f. Two men may be out on a long traverse, in the cabin rover 270-400 nm (435-645 km). Alternately, two men may be out in the small rover or lunar flyer a distance up to 8 nm (13 km) from the base.
- g. Either lunar base will have voice contact with mission control at Earth at intervals of one hour every day.
- h. Rovers and flyers will be based in pairs in the interest of having vehicles to go after crew members in a rescue or other situations.
- i. The lunar space station or an orbital tug will be able to provide communications relay services when the geometry involving it and the rover or flyer concerned is appropriate.
- j. Earth stations are available for communications relay at all times.

THE MAJOR HAZARDS

- 1. Failure of communications (receiving or transmitting or both) in flyers, rovers, or in the equipment of an EVA astronaut in the vicinity of the base, leading to isolation of the crew at a location not well established. This in turn results in the following:
 - a. A lack of vital support and direction from the lunar base
 - b. No ability to call for aid, if needed
 - c. Insufficient information at the lunar base to carry out a rescue mission if that is required
 - d. This could lead to initiating an unneeded rescue mission.

Effects of Critical Communications Failure

- 1. Critical communications failure is assumed to be loss of ability to transmit or to receive or both. A crew on traverse is deprived of com-

munication support from the base for navigation, function monitoring, and advice, while the base may be unable to receive a call for assistance. The base may lack information concerning crew location, particularly if the crew has continued to move since the last report or has headed back for the base following the failure.

Corrective Measures

A basic philosophy that is proposed for communications is that, except for operations where outside help or a safe haven are very near at hand (e.g., EVA within 1 nm of the base), a surface mission will be aborted following any failure reducing communication capability to one normal mode plus a backup. Thus a traverse mission beyond 1 nm would never start with less than one primary, one secondary, and one backup communication system. For the exception where help or haven are near at hand a primary system plus a backup would suffice, with the activity aborted following failure of either system. Contact may be direct or through orbital, Earth based, or lunar surface based relays as appropriate. Failure detection and warning must be provided.

In the event of partial or total loss of communications while on a traverse with either type of rover or the flyer, plans shall exist concerning actions to be taken by the crew on traverse, by the lunar base, and by lunar orbital spacecraft and/or the Earth mission-control. In general, the loss of primary or secondary communications will automatically lead to an abort of the mission.

For a situation where communications are totally lost, plans will exist to ascertain whether or not a crew on traverse stays at a fixed location to await rescue or starts back to the lunar base under directions preplanned for that eventuality. Similar planning will exist for an EVA astronaut in the immediate vicinity of the base.

Escape/Rescue Requirements

1. If the primary or secondary communications systems fail, the flyer's or rover's mission must be aborted.
2. If all communications fail for an EVA astronaut on a rover or flyer mission, rescue is required.

HAZARD STUDY 29
SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. Each EVA astronaut in the vicinity of a lunar base shall have primary, secondary, and emergency backup communication systems.
2. An EVA astronaut shall start a return to the base immediately following a failure of either primary or secondary communications.
3. Each rover and flyer shall have independent primary and secondary communication systems. For traverses beyond 1 nm from the base, an emergency system shall be added.
4. Rover and flyer traverses beyond 1 nm from the base shall be aborted immediately following any communications failure which reduces the total capability to two transmitters and two receivers.
5. Plans for action to be followed in the event of partial or complete communications failure shall be prepared prior to any mission. Plans will be revised as necessary during the mission.

HAZARD STUDY 30
COMMUNICATIONS ASSOCIATED WITH SPACECRAFT IN LUNAR ORBIT

INTRODUCTION

The establishment of high grade, reliable communications is basic to the operation of manned spacecraft in lunar orbit. Such communications will be carried not only among spacecraft in lunar orbit and to Earth stations but also, once surface missions start, with vehicles and bases on the lunar surface. Eventually, surface traffic will appear on the far side of the Moon. This will then increase the need for communications facilities in lunar orbit and/or require a comsat at the L_2 libration point.

ASSUMPTIONS

1. Early communications following manning of an orbiting lunar station will be carried out among lunar orbital spacecraft and Earth stations. After about 6 months of activity in lunar orbit, sorties to the lunar surface will be initiated at regular intervals and communications will be expanded to include the surface activities.
2. Each orbital spacecraft has a minimum of two independent communications systems, following past and current practice for manned spacecraft systems. Additionally, astronauts that engage in EVA from the spacecraft will have a primary and a secondary communications system.
3. No situation ever exists which causes all lunar orbital spacecraft to lose all of their communications simultaneously.

THE MAJOR HAZARDS

The major hazards identified are:

1. An EVA astronaut has a malfunction of his primary and secondary communications system leading to isolation of all information about him from the

lunar space station or other spacecraft from which he egressed. The astronaut cannot call for aid if he needs it, except by the use of hand signals if he is in sight of personnel aboard his monitoring spacecraft.

2. One of the space tugs in lunar orbit loses all of its communications capability; as a consequence other lunar spacecraft whether on the surface or in orbit can no longer send or receive information to or from that tug. The tug cannot call for aid or information if needed. This would be a crucial situation should a rescue be underway.

ANALYSIS OF IDENTIFIED HAZARDS

Effects of Hazard 1, EVA Astronaut's Communications Loss

Loss of communications leads to a lack of information exchange between EVA astronaut and the spacecraft from which he is operating. The information includes both voice communication and monitoring of the vital signs (life functions) of the astronaut, thus knowledge about astronaut well-being is not constantly available. Nor can the astronaut call for aid if he should have such a need. Hand signals could occasionally alleviate the latter problem.

Corrective Measures for Hazard 1

Preventive measures:

1. Provide two independent, highly reliable, communications systems for each EVA astronaut.
2. Communications should be continually monitored by crewmen in tug or space station.
3. Use the EVA buddy system.
4. Check communications at frequent, fixed intervals.

Remedial Measures:

1. Provide an automatic alarm in case of circuit failure in either voice or vital signs monitoring.
2. The EVA astronaut should return to the station immediately following knowledge of failure of either primary or secondary communications.
3. Separately powered blinker light signals should be used to indicate distress.

Escape/Rescue Requirements for Hazard 1

Primary measure is for EVA astronaut and monitoring spacecraft to recognize lack of communications and to get a signal to the astronaut to tell him to return to his spacecraft immediately. If astronaut's alarm does not work, and a light signal or jerk on the tether does not alert him, then another astronaut is required to go out and get the crew member whose system has failed.

Effects of Hazard 2, Loss of Communications in a Space Tug in Lunar Orbit

Communications are lost by a space tug due to a hardware failure within the subsystem or a failure generated by a meteoroid strike. As a result, the tug crew is isolated from all other personnel in the lunar complex so that the crew's well being is in doubt. The crew can neither ask for nor receive directions for the activity that they are engaged in during the communications blackout. Should this particular tug suddenly be needed for an urgent operation it will not be available since it cannot be called via the communications net. If such a loss occurred during a rescue mission, the rescue itself will be endangered.

Corrective Measures for Hazard 2

Preventive measures:

1. Provide independent, highly reliable primary, secondary, and tertiary communication systems on each space tug.
2. Check communications at frequent, fixed intervals.
3. Carry critical spare parts, and schedule preventive maintenance and replacement.

Remedial measures:

1. Provide on-board repair or replacement capability.
2. Return the tug to the orbiting space station for repair following failure of any one communication system, if on-board repair capability is not adequate.
3. Provide coded external light beacons on the tug for emergency backup signals.

Escape/Rescue Requirements for Hazard 2

None required.

Further Discussion

A communications loss for the lunar space station is not deemed to be a major hazard because of the following:

1. The station will have a multiplicity of communications systems aboard which are independent of one another.
2. The antennas for these communications systems are expected to be widely separated on the station and there is expected to be duplicate antennas.
3. All communications systems (as is true for other subsystems) are expected to be checked out on a regular basis with preventive maintenance applied as required to keep all subsystems operational.

4. The lunar space station is expected to have multiple spares aboard for all critical parts of the communications system. Some repair capability is expected to be available in the station as well.
5. In the unlikely event that all of its radio communications fail, the station could operate its communications from a tug docked to it.

HAZARD STUDY 30
SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. Each EVA astronaut shall have independent, highly reliable primary, secondary, and emergency backup communications systems. Loss of the primary system yields an immediate and mandatory requirement for the astronaut to return to his spacecraft.
2. For circuit failure of his primary communications system, it is recommended that an independent alarm be set off for the EVA astronaut.
3. It is strongly recommended that EVA activity be carried out using the buddy system, or the presence of a safety man.
4. Communications with an EVA astronaut shall be monitored and checked at frequent fixed intervals by a crewman in the nearby tug or space station.
5. Provision shall be made to signal an EVA astronaut that his communications have failed. Suggested signals are lights and jerks on the tether.
6. Each communication system shall be checked at frequent fixed intervals.
7. Each space tug shall have a minimum of three independent, highly reliable communication systems.
8. All space tugs shall have external beacons (lights) for use as a backup signalling device.
9. Each space tug in lunar orbit shall be able to dock to the space station in order to re-establish communications by using the station facilities, or by having repairs made to its own system, or by a combination of these methods.
10. The tug shall be returned from an orbital mission to the orbiting lunar station for repair following any communications failure that cannot be corrected on board.
11. The lunar space station shall have some capability to perform scheduled maintenance, and repairs and replacement for communications subsystems.
12. Space tugs should be designed to be able to act as the emergency communications center for the lunar space station.

13. For each specific type of failure a 'flight' plan shall be prepared giving the course of action to be followed for each eventuality. These plans shall be a function of the kind of failure (e.g., lifetime exceeded, meteoroid strike, collision with orbital debris, etc.), the location of the spacecraft, the operational scenario, the degree of availability of external assistance, etc.

HAZARD STUDY 31
RADIOLOGICAL HAZARDS - NATURAL AND MAN-MADE

INTRODUCTION

The innate curiosity and inquisitiveness of man, which, through the ages has driven him into the exploration of regions beyond his local horizon and sphere of knowledge, has also continually exposed man to new and often hazardous environments. Sometimes, when the new environment and acquired knowledge are useful he carries it with him into further quests and ventures, as in the case of new energy sources upon which he can rely for survival and transport. Thus, he must often reassess the sum total of his hazard burden, the hazard potential of the things he takes with him and the potential hazards he faces in a region that is new and of which he has only very limited knowledge.

This study area considers the natural and man-made radiological hazards associated with manned exploration operations in the lunar environment.

ASSUMPTIONS

1. The natural primary radiation environment in lunar orbit and on the lunar surface is taken to be as defined in NASA TM X-53865. Solar particle event data is to be taken from the same reference work (Ref. 1).
2. It is assumed that the man-made sources of hazardous ionizing radiation employed in lunar exploration will consist of the following:
 - Microwave equipment
 - Laser equipment
 - X-ray equipment
 - Radioisotopic power generators
 - Nuclear power plants
3. It is assumed that for the normal operating situations, all man-made sources of hazardous ionizing radiation are adequately shielded,

- contained, or oriented, such that essentially no dose is delivered to operating personnel or personnel in the vicinity of the operating device.
4. For a given crew, it is assumed that solar flare dose effects (where applicable) are accrued in the first several days of the crew tour of duty.
 5. Crew exposure limits utilized for the analysis are the "anticipated crew radiation limits" currently being considered by the NASA-Radiation Constraints Panel as a revision to the "Provisional Radiation Dose Limits for Manned Space Flight Beyond Apollo." (Ref. 2)

The hazard generators considered in this study area are necessarily restricted as to energy type and are discussed only in terms of general attributes. The generators of concern are as follows:

1. Natural sources:

- a. Galactic cosmic radiation
- b. Solar flare particle radiation

The characteristics of (and the distinction between) galactic cosmic radiation and solar flare particle radiation is given in Table 1.

2. Man-made sources:

- a. Electromagnetic radiation - as encountered from microwave, laser, and x-ray radiating equipments.
- b. Nuclear Radiation - consisting of high energy alpha, beta and gamma emissions from unstable isotopes, whether the product of a fission process or simply the decay of a radioisotope species.
- c. Radiological Contaminants - as characterized by the release to the environment of nuclear isotopic materials either as mixed fission products (gases and/or solids), or, as specific isotopic species.

Table 1

Distinctions Between Galactic Cosmic Rays and Flare-Produced High-Energy Solar Particles

CRITERION	COSMIC RAYS	SOLAR PARTICLES
Spatial distribution	Isotropic beyond terrestrial influence (no preferred direction of arrival).	Non-isotropic at onset, later becoming diffused through solar system.
Composition	Approximately 83% protons, 12% alpha particles (helium nuclei), 3% electrons, 1% electromagnetic radiation (gamma), and 1% nuclei of heavier elements to atomic number 26 or 27.	Almost all protons, some alpha particles, no evidence for heavy nuclei.
Temporal variations	Permanent phenomenon, practically constant with time.	Transient radiation, greatly variable with time.
Energy	Range of 10^8 ev to 10^{19} ev in some cases (much greater maximum than solar particles).	Range of 10^9 to 5×10^{10} ev.
Origin	Theories only; perhaps supernovae explosions in the galaxy.	Active regions of flares on the sun.
Intensity	Relatively low; about 2 particles/cm ² /sec of all energies.	Very high; may be as high as 10^6 particles/cm ² /sec during infrequent periods of solar activity.
Biological effects	Primarily chronic; perhaps some vital cell destruction.	Primarily acute damage; possible sudden illness, incapacitation, or death.

Ref. 2 and 3

THE MAJOR HAZARD

The major hazard which can potentially be generated by the natural space radiation environment and man-made nuclear energy conversion devices is the exposure of man to levels of high energy radiation which could exceed or exceed established crew radiation exposure limits. The magnitude of the potential hazard ranges from small incremental increases in crew total radiation exposure to large dose burdens which could be physiologically intolerable to the crew's health and well being.

ANALYSIS OF THE MAJOR HAZARD

The major hazard of concern then is the exposure of man as a biological entity to ionizing radiation which is known to degrade and produce injury at the basic molecular and cellular level in the human organism. The most singular attribute of the radiation exposure hazard is that the presence of a radiation field is normally not apparent to man. In fact, its presence cannot usually be sensed by man until the energy input involved is well into regions where exposure has already begun to fatally injure the man. Fortunately, however, man has learned to detect the presence of radiation with a wide variety of detection instruments which can sense and measure the type and intensity of the radiation field. Man is therefore very much dependent upon such instrumentation to keep him aware of the radiation environment around him. A second and very significant attribute of the radiation exposure hazard derives directly from the practically instantaneous rate changes which can occur in exposures from malfunctioning or breached man-made sources. A similar attribute is characteristic of solar flares, although the rate changes are a matter of minutes rather than milliseconds.

The principal exposure mechanisms which present a potential radiation hazard are the following:

1. Natural Sources -

- a. Galactic Cosmic Radiation - a relatively constant flux of low intensity and isotropic distribution.

- b. Solar Particle Events - sporadic proton showers resulting from sudden and sometimes unexpected solar flare activity. While sun activity cycles are generally known, specific flare activities within the cycle are unpredictable. A worst case situation would be a prolonged flare exceeding 1-2 days with unexpected intensity magnitudes.

2. Man-Made Sources -

- a. Microwaves - exposures to beam power densities close to or exceeding .1 watts/cm² producing a thermal biological response.
- b. X-Rays - Faulty shielding of high power electron tubes (Klystrons, etc.). Cumulative stray exposure from x-ray type analytical tools.
- c. Laser Beams - inadvertent exposure to high energy beam or pulses of laser type equipments. Exposure of eyes to moderate energy beams of low intensity laser equipment.
- d. Radioisotope Thermoelectric Generators (Ref. 6) -
 - (1) Alpha Emitters (Plutonium-238, Curium-242, or Polonium-210) - Burns resulting from inadvertent contact with heat capsule during assembly; or, Alpha contamination resulting from rupture of heat capsule.
 - (2) Beta Emitters (Strontium-90) - Exposure to gamma radiation if RTG shielding is breached. Beta emitter contamination if source capsule is ruptured.
- e. Nuclear Electrical Power Systems (Ref. 7) -
 - (1) Ambient radiation environment around reactor compartment.
 - (2) Loss of Reactor compartment shield integrity.
 - (3) Leakage of fission products into heat transfer system outside of reactor shield.

The Hazards Effects

The effects of the major hazard upon man have been extensively studied for a number of years. A recent work (Ref. 5) has rather thoroughly examined the effects of radiation upon man as such effects relate to manned space flight. The authors concluded that, practically speaking, a "threshold of damage"

concept for radiation effects upon man does not per se exist, and further, that any amount of radiation contributed in some extent to "life shortening" for man. Hence, any "exposure limits" criteria would have to reflect the concept of - "the price you want to pay for the activity you want to accomplish"-type of philosophy. While this is probably true in the absolute sense, there is also available other data which indicate that for select populations working to controlled radiation exposure limits, there has been no noticeable difference in general longevity or general health.

Based upon available information from many sources, the NASA-Radiation Constraints Panel has set forth a table of values for allowable crew exposure limits published as the "Radiation Dose Limits for Manned Space Flight in Skylab, Shuttle, and Space Station/Base Programs" (Ref. 9).

TABLE 2
RADIATION EXPOSURE LIMITS AND EXPOSURE RATE
CONSTRAINTS FOR UNIT REFERENCE RISK (rem)

EXPOSED AREA DEPTH	1 YR. AVG. DAILY	30 DAY	QUARTERLY	YEARLY	CAREER
SKIN (0.1 MM)	0.6	75	105	225	1,200
EYE (3 MM)	0.3	37	52	112	600
TESTES (3CM)	0.1	13	18	38	200
MARROW (5 CM)	0.2	25	35	75	400

Table 2 provides the measurement basis for evaluation of the radiation exposure rate-time effects upon the crew in terms of total exposure accountability.

1. Natural Sources Effects:

The exposure of lunar exploration personnel to the lunar ambient cosmic radiation fields and the effects of solar flares upon cumulative crew dose burden may be estimated utilizing data from the NASA TM-X-53865 (Ref. 1). Figure 1 presents a plot of the Ref. 1 data superimposed upon the crew exposure limits taken from Table 2. The data are given for the

nominal cosmic radiation field and for the nominal cosmic radiation field plus a solar flare event. The curve assumes that the solar flare occurred on the first day of crew residence in lunar orbit. The effects of two different shielding densities are included in the data. Figure 1 rather pointedly illustrates the necessity for a well shielded "storm cellar" for limiting crew dose from solar flare events. It is quite likely that shielding in excess of 10 gm/cm^2 will be required for the "storm cellar" shelter area as a guard against multiple successive solar flare occurrences.

2. Electromagnetic Radiation Effects:

Devices such as microwave and laser generators are normally capable of beam power output values greatly in excess of safe human exposure limits even when operated at low power levels. For example, a value of $.1 \text{ watt/cm}^2$ for microwave will produce thermo-biological effects (cooking) in the human body from beam absorption. The normal allowable exposure is $.01 \text{ watts/cm}^2$ for an unshielded man. For lasers operating in the visible light range ($0.4 \mu\text{m}$ to $1.4 \mu\text{m}$), the threshold for eye damage is $1 \times 10^{-5} \text{ watt/cm}^2$ (CW mode) and $1 \times 10^{-6} \text{ joule/cm}^2$ for the pulsed mode.

3. High Energy Radiation Effects:

Devices which generate radiative energy at wavelengths smaller than 10^{-4} mm produce ionizing radiation of increasing energy content as the frequency gets smaller. This phenomena begins with UV, and becomes more pronounced as the x-ray and gamma ray wavelengths are approached. Since the wavelength becomes miniscule it is customary to refer to penetrating ionizing radiation in terms of its energy. The only real difference between x-rays and gamma rays is the photon energy content and the fact that x-rays can be produced by electron bombardment of a heavy metal target and gamma rays are normally the product of a nuclear state decay or disintegration event. For both x-ray and gamma ray emitters the amount of shielding required is dependent upon the photon energy and the device is shielded against the strongest photon it emits.

The effects of x-ray and gamma ray exposure have been studied extensively and accurate dosimetry techniques are readily available for sensing and measuring human exposure in terms of any part of the energy spectrum.

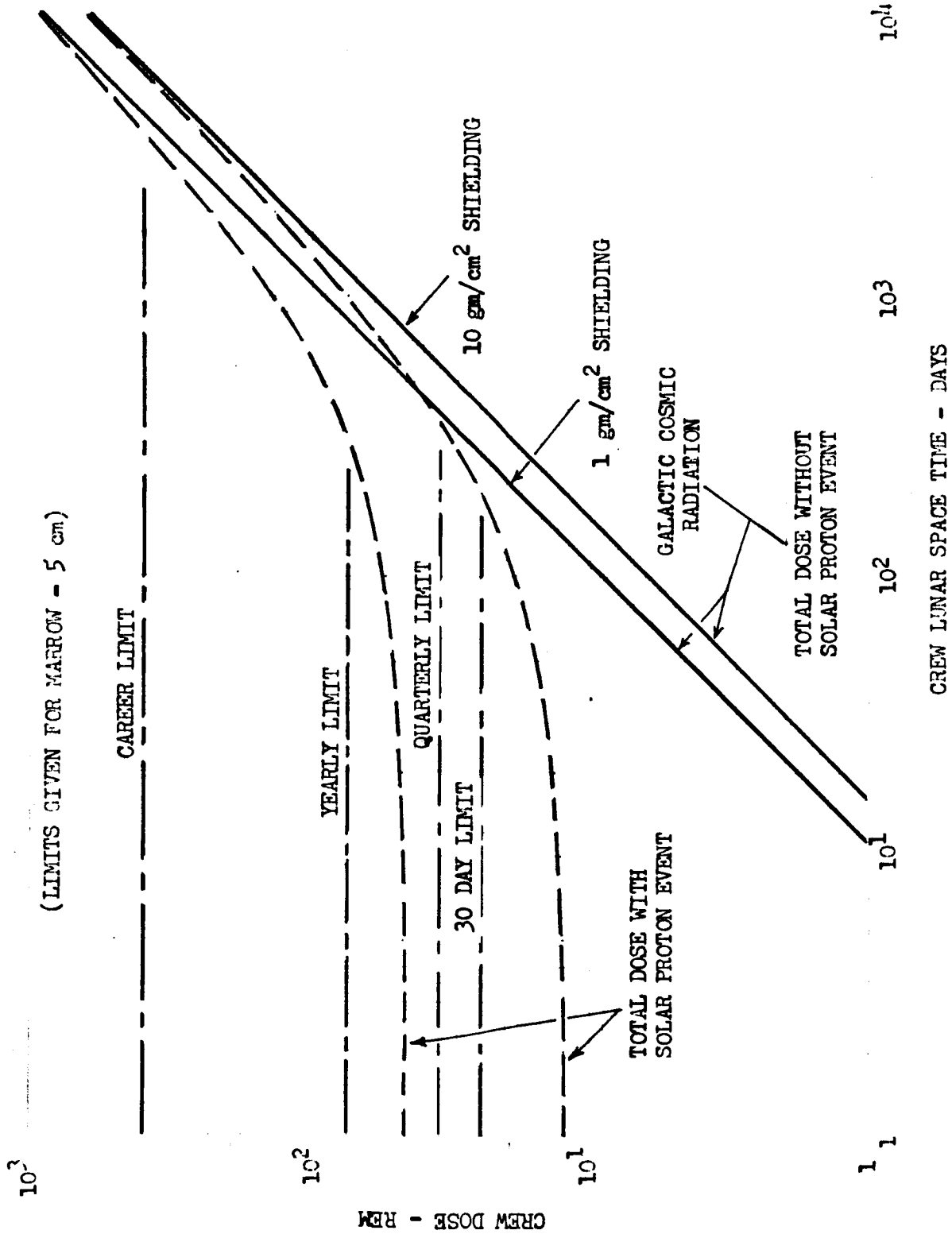


Fig. 1 Crew Exposure Limits and the Predicted Lunar Natural Radiation Environment

TABLE 3

EFFECTS OF ACUTE WHOLE-BODY EXTERNAL RADIATION EXPOSURE AND PROBABLE THERAPY (REF.8)

	0-25 rems	25-100 rems	100-200 rems	200-300 rems	300-600 rems	600 or more
IMMEDIATE EFFECTS	No detectable clinical effects	Slight transient reductions in lymphocytes and neutrophils. Disabling sickness not common; exposed individuals should be able to proceed with usual duties.	Nausea and fatigue, with possible vomiting above 125 rems.* Reduction in lymphocytes and neutrophils with delayed recovery.	Nausea and vomiting on first day. Latent period up to 2 weeks or perhaps longer.	Nausea, vomiting and diarrhea in first few hours. Latent period with no definite symptoms, perhaps as long as 1 week.	Nausea, vomiting and diarrhea in first few hours. Short latent period with no definite symptoms in some cases during first week.
DELAYED EFFECTS	Delayed effects may occur.	Delayed effects possible, but serious effects on average individual very improbable.	Delayed effects may shorten life expectancy in the order of 1%.	Following latent period, the following symptoms appear but are not severe: loss of appetite, and general malaise, sore throat, pallor, petechiae, diarrhea, moderate emaciation. Recovery likely in about 3 months unless complicated by poor previous health or superimposed injuries or infections.	Epilation, loss of appetite, general malaise, and fever during second week, followed by hemorrhage, purpura, petechiae, inflammation of mouth and throat, diarrhea, and emaciation in the third week. Some deaths in 2 to 6 weeks. Possible eventual death to 50% of the exposed individuals for about 500 rems.	Diarrhea, hemorrhage, purpura, inflammation of mouth and throat, fever toward end of first week. Rapid emaciation and death as early as the second week, with eventual death of up to 100% of exposed individuals.
RECOMMENDED THERAPY		Reassurance is probably the only therapy needed.	Patients should be kept under hematological surveillance.	Antibiotics should be administered as indicated.	Antibiotics and blood transfusions should be administered as indicated.	Bone marrow transplantations may be tried. Electrolyte balance should be maintained.
	*Occurs on the first day or so following irradiation, followed by a "latent period" up to 2 weeks or more, during which the patient has no disabling illness and can proceed with his regular occupation. The usual symptoms, such as loss of appetite and malaise, may reappear, but if they do, they are mild.					

TABLE 4

STATISTICS OF EARLY EFFECTS - ACUTE WHOLE BODY IRRADIATION (REF.2)

DOSE IN RADS	VOMITING AND NAUSEA	RADIATION SICKNESS	DEATH
0-50		NO OBVIOUS EFFECTS	
50-100	~ 20%*	MODERATE	—
100-200	~ 50%	SERIOUS	~ 5%
200-350	50-90%, < 1 DAY	SEVERE	5 → 90%, 2 → 6 WEEKS
350-550	~ 100%, < 1 DAY	SEVERE	~ 100%, < 1 MONTH
550-750	100%, < 4 HOURS	SEVERE	~ 100%, < 1 MONTH
1000	100%, < 2 HOURS	SEVERE	100%, < 1 MONTH
5000	100%, < 1/2 HOUR	SEVERE	100%, < 1 WEEK

*PERCENTAGE OF EXPOSED PERSONNEL AFFECTED

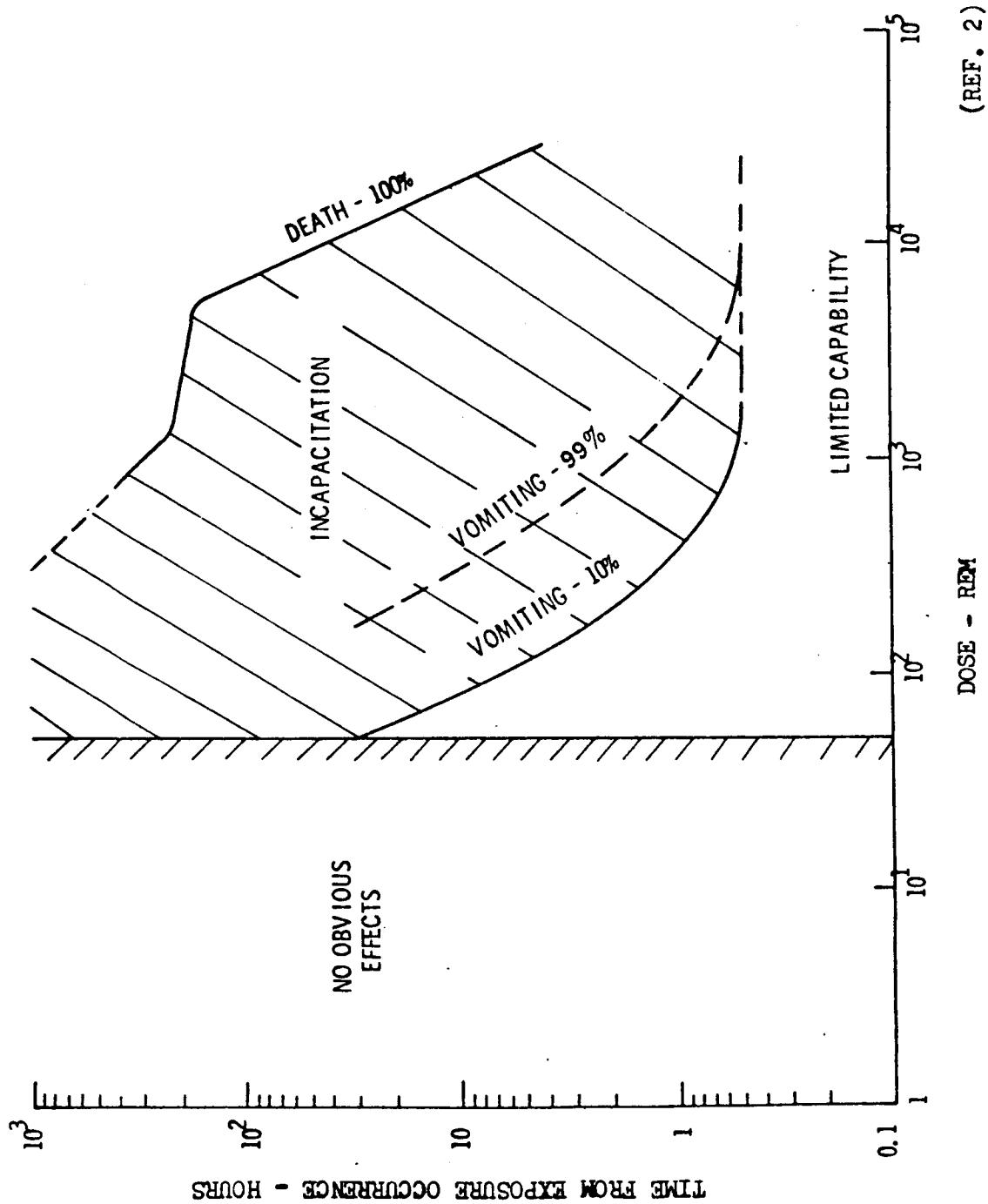


Fig. 2 Early Time Effect - Acute Whole Body Exposure

Exposure accounting techniques are also well developed which provide for each crewman his total exposure burden at any time based upon his sensor badge and dosimeter readings.

4. Particle Radiation Effects:

For devices such as radioisotope thermal generator sources and nuclear fission sources there are additional energy sources to be considered. A radioisotope may decay by the emission of an alpha particle (helium nuclei), a beta particle (positron) and/or gamma rays. Normally the source enclosures are sealed and of sufficient thickness to stop or absorb alpha or beta particles. However, should the enclosures be damaged or breached it is possible to release the isotope source material into the local environment with serious contamination and exposure problems ensuing.

The problem of radiation exposure associated with a nuclear power generator (employing a fission reactor) have been examined in another study area and the reader is referred to Ref. 7 for study details.

5. Gross Exposure Effects:

The major impact of ionizing radiation upon living cells of the human body is the fact that some degradation of the collective cell structure will occur each and every time an exposure occurs. The collective cell structure tolerates and adapts to the low radiation levels found over the Earth's surface. Exposure to higher levels of ionizing radiation over periods of time has been demonstrated to be deleterious to human health as evidenced by numerous medical studies (Ref. 5). Exposure to very high radiation levels even for short periods of time can place the human organism in dire jeopardy as indicated in Tables 3 and 4. The generalized effects of large radiation exposures to crew personnel may be inferred from the data presented in Figure 2. The figure presents the radiation dose versus time since exposure occurrence and provides a rough measure of the degradation of personnel capability with time after exposure.

Corrective Measures

Preventive Measures:

1. The principal means of controlling crew exposure to the natural sources of radiation will be the shielding afforded by the orbiting lunar station, the crew modules, the lunar surface base and the cabin-type rover for surface activity.
2. Protection from the man-made radiation sources must be afforded as an inherent part of the source design. For those sources employing isotopes, fission products, or fissionable materials, double containment must be provided to preclude spillage, leakage, and the contamination of the local environment. (Ref. 9)
3. It must not be possible for crew personnel to activate or energize microwave, laser, or x-ray equipments from positions which expose them to the output of such equipments.

Remedial Measures:

1. Remedial corrective measures for countering the effects of overexposure to the several types of ionizing radiation are largely of a medical nature. Hence, the Orbiting Lunar Station will be required to maintain in the medical kit an adequate minimum supply of emergency treatment drugs and reagents.

Escape/Rescue Requirements

In view of the lack of established guidelines for action to be taken in the event of sudden overexposure to high energy ionizing radiation, the following tentative guidelines are proposed for consideration:

1. For individual crewmen involved;
 - a. Up to 25 REM - Station duty only and Earth return at end of normal duty tour
 - b. In excess of 25 REM but not over 75 REM - Under medical surveillance with possible light duty and Earth return at next opportunity
 - c. In excess of 75 REM - Emergency treatment and prompt return to Earth via tug.

2. For more than two crewmen involved;
 - a. For exposures in excess of 75 REM - Requires immediate return of exposed personnel.

SOURCE DATA REFERENCES

1. "Natural Environment Criteria for the NASA Space Station Program," Second Edition, NASA TM X-53865, D. K. Weidner, Ed., NASA-MSFC, Aug 20, 1970.
2. "Space Base Nuclear System Safety Study," First Performance Review, GESP-7059, General Electric Co., Nov. 24, 1970.
3. "Air Force Systems Command, Design Handbook 1-3, Personnel Subsystems - (Design Note 302)," First Ed., Rev. 3, 1 Jan. 1969.
4. "Air Force Systems Command, Design Handbook 3-2, Space Vehicles, Chapter 2 - Natural Environments, Section 20 - Space Environments (DN-202), First Ed., Rev. 2, 20 March 1969.
5. "Radiobiological Factors in Manned Space Flight," W. H. Langham, Editor, (Report of the Space Radiation Study Panel), National Academy of Sciences, National Research Council, Washington, D. C. 1967.
6. "Guidebook for the Application of Space Nuclear Power Systems," Atomic Industrial Forum, January 1969.
7. "Hazardous Operations In and Around The Orbiting Lunar Station - Nuclear Power Plant," Study Area 4.5, Lunar Mission Safety and Rescue Study, LMSC, 11 December 1970.
8. Air Force Systems Command, Design Handbook 1-3, Personnel Subsystems, Chapter 3, Section 3-D- , Radiation (Design Note 3D2). 1st Ed. Rev. 3 1 January 1969.
9. "Radiation Dose Limits for Manned Space Flight in Skylab, Shuttle, and Space Station/Base Programs", NASA - R. G. Rose, Chairman, Radiation Constraints Panel, memo dated Jan. 15, 1971.
10. The applicable sections of Title 10, Chapter I of the Code of Federal Regulations, (viz Parts 20, 32, 33, 40, 70, and 71) shall be considered as basic source data.

HAZARD STUDY 31
SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. Consideration of "crew radiation-exposure accountability" must be included in the administrative procedures devised for lunar exploration mission planning. It must be possible to update each crewman's exposure record at least once each 24 hours.
2. Serious consideration shall be given to the implementation of a mission planning function which will thoroughly evaluate the "crew radiation exposure potential" for each phase and activity of the planned missions.
3. Specific crew safety studies shall be required for each item of mission equipment capable of emitting ionizing radiation. The studies shall be conducted in the context of the mission(s) for which the equipment use is intended. Where several such equipments are to be employed, the study shall account for the sequential and/or simultaneous use of the involved equipments.
4. All nuclear and isotope source units shall have been demonstrated to be safely contained against impact, weldment leakages, or containment melt-through, prior to flight qualification. Where the unit is to be employed continuously in close proximity to crew quarters and shelters, the unit shall be doubly contained to avoid all possibility of leakage and local environment contamination.

HAZARD STUDY 32

LUNAR SURFACE PHYSICAL CONDITIONS

INTRODUCTION

The subject of lunar surface physical conditions as a source of hazards to lunar exploration personnel is one in which the desk-bound analyst is considerably at a disadvantage. The only human beings to experience first-hand the impact of such physical conditions are the Apollo astronauts. And needless to say, while the lunar samples returned have been priceless as sources of basic composition information, it is impossible to extrapolate from a box of rocks to surface structure. However, we do have an immense quantity of photographic data from the Ranger, Orbiter, Surveyor and Apollo missions which has provided coverage of various kinds of quality for all but a small percentage of the lunar surface. Thus, it is primarily this photography and the the Apollo descriptions (Ref. 1) from which we can at least visualize some of the problems which surface explorers may encounter.

ASSUMPTIONS

1. Photographs which are currently available reasonably represent the seleneology of the lunar surface.
2. Considering the limitations of the seleneological data available to date, including soil mechanics and characteristics observations, it is possible that other lunar regions may exhibit characteristics entirely different. The possibility of surface crust-like formations, sub-surface cavities, vent-gas blow holes, etc., cannot be presently ruled out. Nor is it possible to confirm or rule out, as yet, the existence of active venting sites where lunar outgassing may be observed.

THE MAJOR HAZARDS

The major hazards to lunar exploration personnel associated with lunar surface physical conditions considered to be of significance are as follows:

1. Lunar Dust
2. Lunar Lighting Phenomena
3. Lunar Soil Mechanics Variation
4. Topographical Natural Barriers
5. Meteoroid Strike Frequency

ANALYSIS OF IDENTIFIED HAZARDS

Effects of Hazard 1, Lunar Dust

The impact of lunar dust in manned exploration of the lunar surface has already gained prominence as a troublesome hazard as recorded in the mission reports of the Apollo 11 and 12 crew manhours. That the problem will become more severe with the advent of larger landing vehicles, large rovers, and dual landing requirements, etc., is a foregone conclusion.

Specific effects noted to date have included suit contamination, experiment contamination, and landing craft contamination including cabin atmosphere. The dust, further, was carried into the command module. (Refs. 1 and 2) A concomittant train of contamination is evident and applicable to the proposed tugs and orbiting lunar station (OLS).

The ingestion of lunar dust in any appreciable quantities is likely to be serious from a health standpoint considering the accumulated findings of dust inhalation studies conducted for various earth mining and ore smelting operations. The impact of lunar dust upon rotating and moving machinery is certain to affect rover and surface mobility aid equipment design in the protection of mechanical parts and in providing assurance of visibility for

the operation. Until more is known of the dust depth over various regions of the lunar surface, it must be assumed that deep dust pockets could occur which might contribute to the engulfing or entrapment of personnel or equipment.

The employment of large landing vehicles having multiple engines has been postulated as being capable of creating veritable lunar dust storms in the immediate area of the landing site. Postulated separation distances for dual or sequential landings are currently on the order of one to one and a half miles in order to protect the other vehicle from the sandblasting effects of thrust plume impingement, ejected dust, and small rocks. If such is the case, then a tug rescue of exposed suited crewmen would be further complicated by the tug landing separation distance requirement.

Corrective Measures for Hazard 1

Preventive measures:

1. A design requirement exists for the development of a dust collector applicable to cleaning dust from space suits, equipment surfaces, etc., in external lunar environment conditions. The principle upon which to base such a collector (electro-static, etc.) is not readily apparent, therefore a development requirement also exists. It would be advantageous to improve the design of equipment so that it is not affected by lunar dust. However, establishing a rule for vacuum cleaning of suits and equipment in airlock before entry into main areas would appear to be more cost-effective and safer. Suits and equipment must be cleaned in any case before entry, and dust in the atmospheres of the LSB, tugs or surface vehicles would be, at the very least, an irritant to membranes of the respiratory system.
2. A design and development requirement also exists for dust seal applications on both static and moving equipment components and assemblies employed in lunar surface experiments and mobility aids.

3. The effects of dust cloud size, dispersion distance, and density resulting from large lander landings must be evaluated in terms of potential constraints imposed upon surface rescue missions.

Remedial measures:

1. Provision of small atmospheric vacuum cleaner in atmosphere containing shelters, air locks and crew compartments to trap surface dust from suits in a self-closing contained filter bag or chamber.
2. Provision of two 100 ft. rolls of 3 foot wide highly visible foil with anchor pins or weights to serve as rescue location marker (X) providing reference point for landing separation distance estimation by lander crew in a daylight landing.

Escape/Rescue Requirements for Hazard 1

None are postulated due to exploratory nature of study.

Effects of Hazard 2, Lunar Lighting Phenomena

The effects of lunar lighting conditions upon personnel activities have been noted in some detail in the reports of the Apollo 11 and 12 missions. The importance of sun elevation angle for lunar landings is discussed in Ref. 2 and in Hazard Study 28.

The effects of sun elevation will strongly influence not only landing operations but surface activities as well. It has been reported that the operators of Russia's Lunokhod-1 have experienced visual difficulty at sun angles less than 30° when long shadows tended to obscure small craters and crater depths (Ref. 4). It may also be expected that the exploration of large craters such as Tycho or Copernicus are going to be lighting-condition constrained and will require photographic coverage to obtain sun angle versus crater floor obstacle definition data prior to any attempted landings on the floor.

Rescue missions will also be constrained by lighting conditions prevalent in the vicinity of the attempted rescue. Particularly, if some search effort is required to find the distressed personnel. For periods of direct overhead sunlight (90°), it will be extremely difficult to find either vehicles or men in the "wash-out" created by lunar surface back reflectance of light.

Corrective Measures for Hazard 2

Preventive measures:

1. The potential use of polarizing filters to attenuate reflected light from the lunar surface.
2. The potential application of heliograph type* signalling devices for distressed surface personnel use as a beacon or even for communication.
3. The use of simplified radar ranging equipment to aid in surface rover navigation during unfavorable sun angle periods.

Remedial measures:

1. Provision of a mirror, flare gun, and emergency radio transponder beacon in all emergency kits for parties on surface sortie of any type.
2. Provision of radar reflecting deployable foil in all emergency kits for surface sortie personnel utilization.

Escape/Rescue Requirements for Hazard 2

None postulated for this study area.

Effects of Hazard 3, Lunar Soil Mechanics Variation

The variation of lunar soil types and condition over the surface of the Moon are largely unknown. However, certain kinds of lunar formations such as

* An instrument for telegraphing by means of the Sun's rays reflected from a mirror. It has been adapted for use in the dark with its own lamp.

steep banks, slumped soil areas and rocky mountainous or hilly regions do have familiar counterparts on Earth. The obviously slumped soil formations lining the crater ruins of Tycho, Copernicus, and other great craters may well behave like avalanches if sufficiently disturbed by the rocket engine vibrations of a landing tug descending to the floor of the crater. Or, if disturbed by a moon quake having its origin in nearby regions. The steep banks of most craters and some rilles are likely places also to encounter engulfing avalanches of sliding soil if untethered descent were to be attempted.

The exploration of mountainous regions by suited crewmen is likely to be limited only to those sites where a lander can be set down, since current suit technology permits neither long time sorties nor the high metabolic rates associated with mountain climbing. Hilly regions may be navigable by a large rover at least to the extent that the winding valleys can be penetrated. The problem of unknown variations in surface soil structure will only become known by surface exploration. Such phenomena as surface crusting with variable load support strength, and the possibility of sub-surface cavities, may exist in the regions which are thought to be volcanic in origin. The detection of these soil surface and sub-surface formations requires both seismic and sounding equipments as well as surface penetrometer measurements. Visual evidence of such phenomena may well be obscured by lunar dust layers. Evidence of fault bridging, a form of crusting, may only become apparent when the exploring vehicle falls through the bridging soil crust, unless suitable detectors are available.

Corrective Measures for Hazard 3

Preventive measures:

None postulated due to lack of specific soil problem data.

Remedial measures:

None postulated due to lack of specific data.

Escape/Rescue Requirements for Hazard 3

None identified due to the general nature of this study area, but soil mechanics may well generate a situation requiring rescue.

Effects of Hazard 4, Topographical Natural Barriers

The natural barriers which are of importance to surface travel are readily apparent from lunar maps which include elevation measurements. Most of the major craters appear to be in the group requiring lander operations for accessibility to both rims and floor areas. Surface equipments simply could not scale the heights on such rugged terrain. Other lunar prominences include mountains which on the near side of the moon reach up to 39,500 feet in altitude. No doubt there are equivalent heights or higher on the far side. Such mountains could pose a hazard if a planned landing trajectory were to cross the region at low altitude.

Corrective Measures for Hazard 4

Preventive measures:

1. Operational planning for both descent from orbit and for surface activities must include detailed information relative to the natural lunar surface formations with respect to elevation, shortest path around barriers, and regions where accessibility is restricted.

Remedial measures:

Not applicable to this study area because of lack of mission data.

Escape/Rescue Requirements for Hazard 4

Not considered for this study area.

Effects of Hazard 5, Meteoroid Strike

This hazard requires further study due to the lack of definitive data. The relative frequency of surface meteoroid strikes could well be different for definable regions of the Moon and may well be influenced by the regions of meteoroid origin. Therefore, the hazard is only set forth as a subject requiring further study prior to the initiation of a lunar exploration program. Relevant data available is summarized in Ref. 5. No corrective measures are postulated and no escape/rescue requirements are specified.

RECOMMENDATIONS FOR FURTHER STUDY

1. A study is required leading to the selection of a technique for the collection of lunar dust from the exterior of space suits and equipment surfaces. The collector (vacuum sweeper equivalent) should be capable of working in space vacuum conditions.
2. A study is required for the design and development of improved dust seals for static and moving equipment components exposed to lunar dust.
3. A study is required to determine the effects of lunar dust dispersal created by larger lunar landers. The effects of the dust dispersal upon adjacent vehicles and/or parties to be rescued is to be evaluated.
4. A study is recommended for the development of polarizing filters for the attenuation of lunar surface reflected light. The filters would be attachable to windows or suit visors.
5. A study should be accomplished on the use of a heliograph type device for beacon and communication signalling applications on the lunar surface.
6. A specific study is required that involves the planning of early lunar experiments to ascertain the relative frequency of meteoroid strikes to the lunar surface. Further, the study must determine if the relative frequency is constant over all areas or varies with lunar latitude and longitude.

SOURCE DATA REFERENCES

1. "Apollo 12 - Preliminary Science Report," NASA SP-235, (MSC), NASA, Wash. D.C., dated 1 June 1970.
2. Apollo 12 Mission Report, MSC-01855, Manned Spacecraft Center, Houston, Texas, March 1970.
3. Apollo Program (Phase I Lunar Exploration) Mission Definitions, MSC-01266, ASPO/AMPO, Manned Spacecraft Center, Houston, Texas, 1 Dec 1969.
4. "Tracks of Lunokhod-1 Shown Before Soviets Deactivate It For Lunar Night," Aviation Week and Space Technology, Issue of 4 Jan 1971.
5. "Natural Environment for the NASA Space Station Program," 2nd Ed., NASA TM X-53865, MSFC, Huntsville, Ala., Aug 20, 1970.

HAZARD STUDY 32
SUMMARY OF SAFETY GUIDELINE CONDITIONS

1. Specifically designed atmospheric vacuum cleaners shall be installed in shelters, airlocks, and crew compartments to be used in final clean up of suits after entry and repressurization following lunar surface EVA.
2. Lunar surface sortie parties are to be provided with foil panels (suggested as 100 ft x 3 ft and highly visible in color) which can be unrolled to provide a rescue location visual marker (X).
3. Surface sortie emergency kits shall include at least a mirror (or heliograph), flare gun and emergency radio beacon or transponder for emergency signaling purposes.
4. Mission activity planning shall consider detailed information relative to topographical formations (elevation, etc.) as a necessary part of the OLS data bank. Such information is vital to all landing trajectories in the avoidance of impact with lunar formations which can have elevations of approximately 40,000 ft.

HAZARD STUDY 33

LEAKS IN CABIN WALLS

INTRODUCTION

Leaks in cabin walls can be caused by a variety of circumstances such as a meteoroid hit, secondary ejecta from the lunar surface, failures due to overloading structural components causing cracks and punctures, degradation of elastomeric seals in vacuum, distortion of sealed surfaces due to heat, explosion, collision, vibration, etc. The result in each case is loss of cabin atmosphere at a rate dependent on the size of the opening and the internal pressure.

ASSUMPTIONS

It is assumed that all manned cabins have a certain inherent leakage rate which has been accounted for in the design of the vehicle, for which make-up atmosphere is provided; non catastrophic leakage over the prescribed allowable is what we are concerned with here. Catastrophic rapid decompression caused by violent rupture is not the subject of this study area.

THE MAJOR HAZARD

The major hazard identified is a serious loss of cabin atmosphere through a cabin pressure wall.

ANALYSIS OF IDENTIFIED HAZARDS

Effects of the Hazard

Loss of cabin atmosphere will lead to illness or death due to shortage or absence of breathing oxygen, unless timely corrective action is taken.

Corrective Measures

Preventive measures:

1. Provision of a leakage detection system which provides audio and visual warnings to the crew to enable them to quickly locate the source of the leak and concurrently make a rapid determination of the leakage rate. The latter consideration is a parameter the crew needs to know very quickly in order to decide whether there is sufficient time to repair the leak without having to don space suits. The amount of time available to the crew, for a typical space cabin of 1000 ft³, can be seen in Fig. 1 which shows available time to decompression for 7 and 10 psia cabin pressures with holes varying in diameter from .10 inches to 2.0 inches. Table 1 lists some leak detection methods suggested in Reference a.
2. It is estimated that meteoroid strikes on a cabin wall producing a 1/16" diameter hole will be readily detectable by eye due to the local deformation of the surrounding sheet metal structure; therefore, detection of the location of a strike would be made simpler and quicker if cabin walls are kept clear of equipment.
3. Provide a minimum of two separate living volumes each large enough to accommodate the entire crew.
4. Consider providing a self sealing wall.

Remedial measures:

1. Repair the damaged walls. Depending on the type and size of the damage a variety of repair methods have been suggested. Most of the methods involve the application of a room temperature setting, fire proof rubber or plastic sealant alone or in combination with plugs, patches, tapes applied to the pressure side of the wall. Other ideas include the use of self-sealing walls or self-brazing plugs. For awkward corners a repair patch of sheet-metal customized to fit the damaged area and with

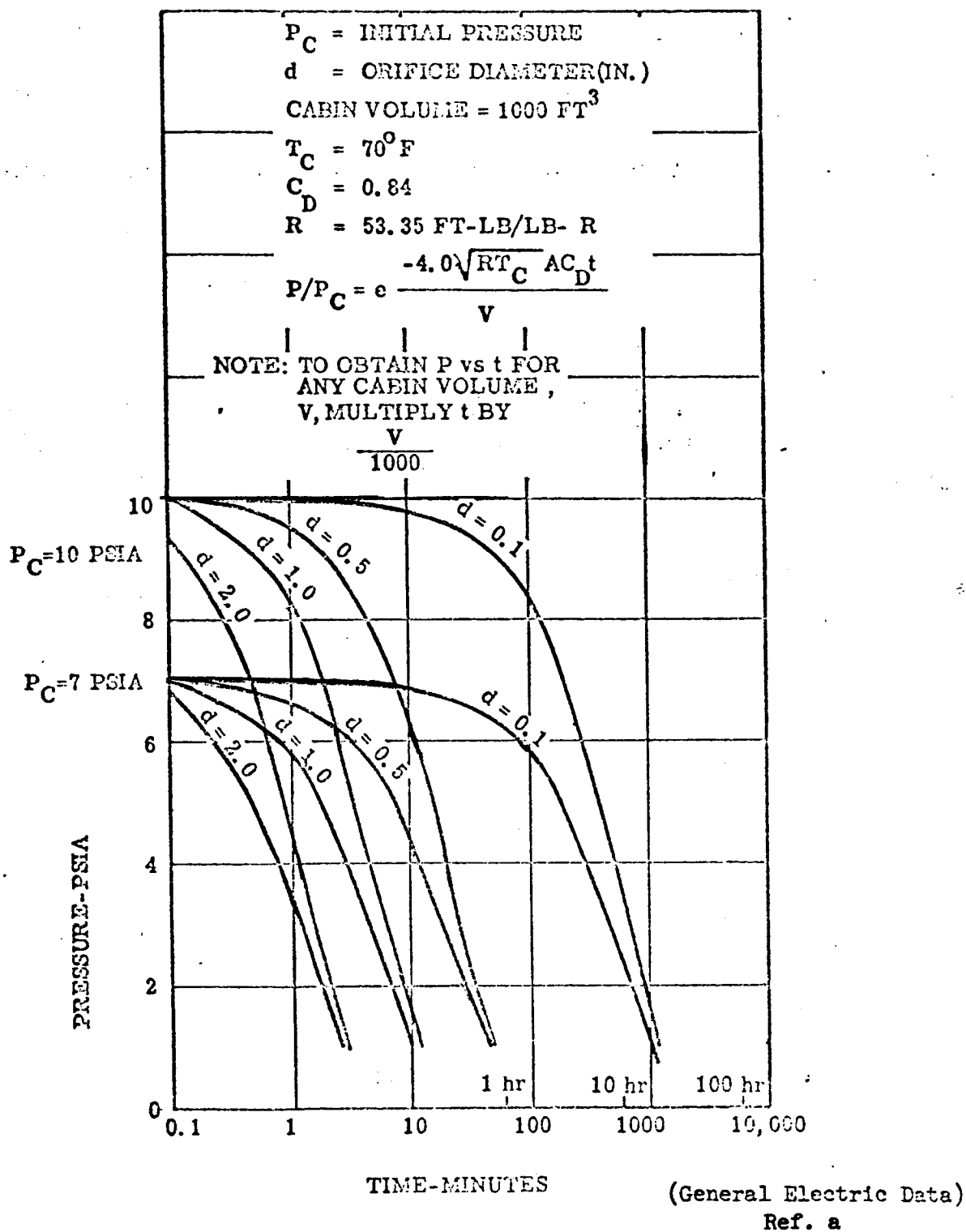


Figure 1. Pressure Decay - Standard Air Composition

Table 1
LEAKAGE DETECTION METHODS

METHOD	DESCRIPTION
P_{N_2} decay on N_2 utilization (Requires location detector)	Determine leak rate by turning off the N_2 make up supply & measuring partial pressure drop
Acoustic (requires large numbers of detectors)	Acoustic pick-ups located in cabin wall, to detect the sound of air escaping
Ion Gauge (requires large numbers of detectors between cabin wall and bumper)	The ion gauge measures pressure changes in the cavity of a double wall structure. It can determine size of leak and approximate location
Visual inspection (requires visual access)	Use of grid lines would help identify location of bulge or damage
Acoustic sniffing	Scan cabin walls with ultrasonic detector
Helium sniffing	Scan walls, seals with helium jet and measure electrical current change in detector
Stress coat paints	Paint distorts in an easily observed manner
Dyes	Paint suspected areas to expose cracks

sealant all around it would do the job. For larger holes 1/2" or more, a patch should be installed with sealed blind mechanical fasteners, using a sealing compound between faying surfaces. (Ref. a)

It is recommended that research be conducted to determine methods of signaling the crew that repairs are needed for walls punctured by a meteoroid. For example, a paint such that exposure to meteoroid shock would change its color would be desirable. Equally important is research to ascertain puncture repair methods that are easy to institute and which require minimal time to execute.

Escape/Rescue Requirements

No escape/rescue requirements are identified for repairable leaks in cabin walls.

DATA SOURCE REFERENCES

- a. Repair of Leaks in an Aerospace Environment, ASD-TDR-62-1015.
Feb. 62. J. Withey. General Electric, Philadelphia, Pa.

HAZARD STUDY 33
SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. Instantaneous warning and detection/location information for cabin leaks above nominal shall be provided.
2. Maximum feasible access to the cabin pressure walls, ceiling, and floor shall be provided in all space vehicles in order to expedite repair of leaks. Insofar as it does not seriously compromise equipment functions, all equipment should be mounted away from vehicle, spacecraft, and base pressure-containing walls in order to permit such access as will be necessary for repairs.
3. Provide capability for supplying emergency oxygen, within seconds, to all crew members, in the event of excessive leaks in a space vehicle cabin.
4. Kits and procedures for repairing damaged cabin walls shall be provided.
5. It is strongly recommended that, where technically feasible, a minimum of two separate but interconnected pressure volumes, each capable of accommodating the entire crew, be provided on all space vehicles.
6. The development of self-sealing walls should be considered.

HAZARD STUDY 34

HANDLING OF HAZARDOUS MATERIALS

INTRODUCTION

In any exploration type program the equipments and materials required to obtain useful information will include a quantity of a so-called hazardous materials. This group of materials may range from pyrotechnics through explosives and from water to acids, bases, and cryogenic liquids, and may include quantities of elemental gases and radioisotopes (Ref. 1). Similarly, the lunar exploration program will involve the use of a great many materials which basically may be classed as hazardous (Ref. 2). Additionally, some of the materials used and not considered hazardous on Earth may well prove to be hazardous when employed in the lunar environment and/or under zero-g conditions. For example, in zero-g water tends to form a thin layer on surfaces and penetrates spaces amongst electronic equipments causing short circuits. Therefore, water floating free in a cabin is hazardous.

ASSUMPTIONS

1. Mission exploration and science requirements include necessity for stores of ordnance, cryogenics, chemicals, fuel, and life support items such as high purity cryogenic oxygen. (Ref. 2).
2. Emergency safety equipment largely is adapted from NASA and USAF experience for safety equipment and procedures. (Ref. 3 and 4).

THE MAJOR HAZARDS

The major hazards identified are:

1. Improper procedures in handling of materials or accidents in such materials handling.

2. Unsecured cargo and equipment including hazardous materials.

ANALYSIS OF IDENTIFIED HAZARDS

Effects of Hazard 1, Improper Handling or Accidents With Hazardous Materials

The hazards occasioned by improper handling are applicable to all stores and specifically applicable to hazardous materials.

The improper, abusive, or careless handling of such materials ranges from storing fuel and oxidizer materials in the same compartment to the storage of seismic ordnance at the end of a passage way where it can be rammed by cargo being moved. Improper handling also includes the failure to store life support materials away from hazardous chemicals, gases, and propellant materials in order to avoid contamination (Ref. 5), and loss by fire or explosion.

The consequences of failing to understand and follow specific handling instructions based upon the known physical and chemical properties of various stores could lead to fire, explosion, emission of toxic contaminants and metabolic deprivation, usually in rapid order. An event such as the emplacement and connection of seismic ordnance charges with suit transmitter energized could result in loss of a crewman.

The hazards effects resulting from improper safeguards in the handling of hazardous materials are closely related to improper handling effects but carry the connotation of carelessness and negligence rather than inadvertent oversight. The employment of safeguards is a deliberate step inserted into a procedure to enhance the safety of an operation, and the implied purpose is to establish a safety action which flags the operation as dangerous. Therefore, the omission of a safeguard action may be defined as a conscious or unconscious willful disregard for the safety of the specified operation. Examples of simple safeguards are signs which read

"do not stack" or "vent before opening." More sophisticated safeguards may involve the installation of a specifically designed safety valve prior to rupturing a safety seal to obtain access to a toxic material, or, the connection of an overboard venting device prior to refueling a satellite. The consequences of failure to observe safeguard requirements range from endangerment of the crewman and other personnel to outright catastrophe.

Corrective Measures for Hazard 1

Preventive Measures:

1. The following control measures must be implemented in planning for the handling of hazardous stores:
 - (a) Specific container design for each type store - clearly marked.
 - (b) Specific location in OLS, Tugs and LSB for each type of store material - clearly marked.
 - (c) Specific handling instructions and training for all lunar personnel.
 - (d) Specific mission activity study to ascertain optimum safe location for stores in each vehicle.
 - (e) Establishment of mission stores check list and accountability list for supplies control.
2. Perform vehicle, station and base design reviews specifically to examine the stores storage safety features and to assess the hazards effects countermeasures incorporated (i.e., fire, leakage, explosion, vapor corrosion, contamination, etc.).
3. Early initiation of design and development of specific stores containers affording maximum protection and shelf life to various hazardous stores.
4. Early initiation of development of zero-g lab equipment for handling of toxic, corrosive and ordinary fluids without loss or escape of fluids and gases into closed atmosphere of orbiting stations.

5. Specific training of personnel in the use and purpose of all safeguard procedures and equipments.
6. Incorporation of safeguard devices into design of equipment and containers requiring such devices. (This eliminates possibility of device not being used.)
7. Require "buddy system" in handling and use of hazardous materials to insure compliance with safeguard procedures and assure aid if an accident does occur.
8. Require mandatory review of all hazardous material applications for program needs to insure:
 - (a) Necessity of material use.
 - (b) All hazard aspects are known.
 - (c) Safeguards are more than adequate.
 - (d) Procedures for use are documented and thoroughly understandable.

Remedial Measures:

1. Medical equipment should be maintained in all areas of the lunar complex, where hazardous materials are handled, to treat injuries.
2. Personnel of the lunar complex should be trained to treat injuries due to mishandled hazardous materials. Medical handbooks on such treatment should be readily available in the lunar complex.

Escape/Rescue Requirements for Hazard 1

Escape/Rescue requirements are not specific, but may range from needing assistance in cleaning up a leaking container to escape or rescue from a disaster.

Effects of Hazard 2, Improperly Secured Hazardous Material

The hazard effects arising from unsecured or improperly secured cargo and equipment containing hazardous materials range from simple broken or damaged

outer containers to fire and explosion caused by released hazardous materials. The exposure of personnel to loose containers in zero-g can result in physical injury or fatality from impact and crushing. Structural damage from impact is also quite likely where the mass of the container is sufficiently large.

The failure to properly stack containers or adequately secure them when transferring cargo on the lunar surface can result in a falling object injury even under the acceleration of 1/6 Earth gravity.

Corrective Measures for Hazard 2

Preventive Measures:

1. The following control measures must be implemented in the planning for cargo stowage involving hazardous stores.
 - (a) Specific bulk cargo containers must be designed to permit ease of handling and securing in all stacking configurations.
 - (b) Containers must provide adequate protection from shock, impact and vibration of hazardous contents.
 - (c) Specific studies of mission activity sequences must be considered when planning bulk cargo location and ease of availability in the respective station, tug vehicles, and surface base designs.
2. Vehicle, station and base design reviews should be performed specifically to examine methods of bulk stores stowage and to assess the hazards effects countermeasures incorporated in the design.
3. Periodic checks of bulk stowage areas should be performed to assure security of cargo.

Remedial Measures

1. Remedial measures are the same as stated for Hazard 1.

Escape/Rescue Requirements for Hazard 2

Not applicable in this study.

SOURCE DATA REFERENCES

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4. Air Force Manual 127-100, Ground Safety, Explosives Safety Manual, Dept. of the Air Force, Wash., D.C., 12 June 1968.
5. AFSC Design Handbook (DH 1-3), "Personnel Subsystems," Chapt. 3, Sect. 3B-Toxicology, Design Note 3B1, USAF, 1 July 1970.

HAZARD STUDY 34
SUMMARY OF SAFETY GUIDELINE CANDIDATES

1. Primary containers for hazardous material shall be designed to permit safe storage and transfer of the contained material under all conditions of use and storage in lunar orbit and on the lunar surface. Ascertain the conditions of safe stowage, handling and use of all materials considered to be hazardous both in lunar orbit and on the lunar surface.
2. Secondary bulk cargo storage containers shall be designed to permit safe transfer and handling of primary hazardous material containers under all conditions of transport to lunar orbit and the lunar surface.
3. The tug vehicle, Lunar Orbiting Station and Lunar Surface Base design reviews shall specifically examine the stores stowage safety features and assess the hazards effects countermeasures incorporated (i.e., fire, explosion, vapor control, contamination control, etc.).
4. Considering mission activity sequences, the optimum manner of stowage for hazardous stores shall be ascertained, consistent with safety and availability for use.
5. The actual need for hazardous materials in achieving mission and program objectives shall be established. For each hazardous material needed, alternate materials shall be reviewed to ascertain the possibility of reducing the hazard potential by alternate selection. Alternate techniques for achieving desired program objective and eliminating the more hazardous materials are extremely desirable.
6. For hazardous materials required, insure and certify (prior to flight approval):
 - (a) Necessity for hazardous material use.
 - (b) That all hazards involved in materials use are known.

- (c) That safeguards provided for material use are adequate for personnel safety.
 - (d) That procedures for material use are accurately documented and thoroughly understandable.
 - (e) That disposal of hazardous material in lunar orbit or on lunar surface can be safely accomplished if necessary.
7. Personnel shall be experienced and trained in the handling of hazardous materials both in zero-g and on the lunar surface.
 8. Hazardous materials shall be stored in specially designated remote area wherever practical.

HAZARD STUDY 35

HAZARDS ASSOCIATED WITH NAUSEA DURING EVA OPERATIONS

INTRODUCTION

A potential hazard to the space suited EVA astronaut is associated with nausea induced by motion effects or illness. Adverse motion effects may occur as a result of vehicle motions associated with lunar rovers or through accidental impartment of undesired motion to an EVA astronaut on a lunar orbital mission. Motion sickness has been of constant concern throughout the space program. Ever since the C-131 zero gravity or weightlessness facility was placed in operation in 1958 at the Aerospace Medical Laboratory, motion sickness has been a recurring problem. The Russian Cosmonaut Gherman Titov was the first to report motion sickness in space flight.

ASSUMPTIONS

For the purposes of this analysis it is assumed that nausea due to illness or motion within a habitable cabin environment with the astronaut in shirt-sleeves is a relatively minor problem to cope with. Of primary concern is the astronaut who is nauseated and vomits within the confines of a space suit during lunar traverses with a small lunar rover or during lunar orbital EVA operations.

THE MAJOR HAZARDS

Vomiting in a space suit introduces the following hazards:

1. Aspiration of expelled particles into the breathing systems.
2. Clogging of exhaust ports of the helmet with consequent impairment of CO₂ removal gas circulation and pressure control capability of the PLSS.
3. Partial or total obscuration of visibility through the helmet visor.
4. Decreased effectiveness in the performance of essential operations required to return the affected astronaut to a safe condition.

ANALYSIS OF IDENTIFIED HAZARDS

A wide spectrum of physiogenic and psychogenic factors contribute to the motion sickness phenomenon. Although astronaut selection and training programs are designed to screen out candidates that are relatively susceptible to motion sickness, there is no foolproof technique for preventing or predicting nausea and its undesirable end effects. Even experienced aircraft flight crew personnel have reported nausea during weightless or zero-g simulation flights. Further, a majority of personnel who have experienced motion sickness difficulties on such flights have indicated a willingness to participate in further flight tests. This brings up the concern that the over-zealous astronaut may similarly disregard the possibility of vomiting in the suit when he is feeling indisposed prior to or during EVA operations.

Forceful and involuntary expulsion of vomitus in the suit may result in the following undesirable consequences in varying degrees:

1. Vomiting is accompanied by rapid and involuntary inspiration of air through the mouth. This may introduce particles of varying sizes into the lungs.
2. Suit/PLSS functions may be impaired. Clogging of the circulation system can affect thermal and humidity control, pressurization and CO₂ and odor removal capability of the PLSS.
3. Expulsion of vomitus in the space suit helmet may partially or totally obscure astronaut vision by coating the visor.
4. Motion sickness is accompanied by a feeling of incapacitation which can be expected to degrade astronaut performance in effecting safety measures, e.g., driving lunar rover back to a lunar shelter or maneuvering an EVA work platform back to an orbital lunar base.

EFFECTS OF THE HAZARDS

The effects of nausea and vomiting during EVA operations are as follows:

1. Curtailment of mission and return to shelter due to impaired vision, general feeling of incapacitation, odors and safety hazards associated with aspiration of expelled food particles or clogging of suit exhaust ports.
2. Death of astronaut if breathing system is impaired by congestion with vomitus.
3. Death of astronaut if CO₂ build-up is caused by clogging of exhaust ports. Inlet ports will remain open due to positive pressure of supply gases.
4. Loss of astronaut cooling if the thermal control system is impaired. This could result in further discomfort, unconsciousness, and possibly death.
5. Loss of pressure control or relief. This could cause over pressurization which may result in suit or PLSS rupture. This failure could further jeopardize astronaut safety.

ALTERNATIVE CORRECTIVE MEASURES

1. Continue and refine selection process of screening out astronaut candidates who are susceptible to motion sickness.
2. Continue the development of drugs to counter onset of motion sickness.
3. Design lunar vehicles for a "smooth ride."
4. Control diet of astronauts prior to EVA activities to preclude large particles of ingested food.
5. Design space suits to provide collection traps to preclude depositing in undesirable locations.
6. Indoctrinate astronauts relative to the hazards of nausea during EVA and caution against participating in EVA operations when indisposed.
7. Incorporate secondary or redundant features to minimize the failure possibilities. For example, a redundant relief valve, located in remote or less vulnerable locations could back up the primary relief valve to prevent over-pressurization.
8. Provide capability to switch to a spare or buddy PLSS if the failure occurs within the PLSS.

ESCAPE/RESCUE REQUIREMENTS

The possibility of nausea followed by vomiting in the EVA space suit is a serious concern. The most effective step in coping with this problem is to observe the "buddy system" during both lunar orbital and lunar surface operations. In this manner an incapacitated astronaut can most expeditiously be escorted to a shelter so that the space suit can be removed.

The "buddy astronaut" could retrieve the disabled EVA astronaut in lunar orbit by means of a maneuvering work platform or comparable mobility/cargo transport aid. On the lunar surface, the "buddy astronaut" could drive a small lunar rover back to a shelter. In cases of severe distress, a lunar flying vehicle, if available, might be dispatched to rescue the disabled astronaut out on a lunar sortie.

For cases where the EVA astronaut became disabled within walking distance of a shelter or MOLAB type vehicle, the "buddy astronaut" would walk the ill astronaut back to the base and assist his ingress activities.

The "buddy astronaut" can share his PLSS with the astronaut in distress if the failure is isolated within the PLSS, and if the distressed astronaut has not vomited. If the latter has occurred then it may be necessary to get past the face mask in order to clear the astronaut's mouth of debris. His suit may need clearing as well.

The astronaut may switch to a spare PLSS.

DATA SOURCES

1. Symposium on Motion Sickness with Special Reference to Weightlessness, Technical Documentary Report No. AMRL - TDR-63-25, June 1963.
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HAZARD STUDY 35
SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. Astronaut candidates must be carefully screened to eliminate personnel who are susceptible to motion sickness or nausea.
2. Training and simulation programs should continue to acclimatize astronaut personnel to the types of extreme motions anticipated with lunar rover traverses or abnormal EVA motions.
3. Lunar vehicle suspension systems should be designed for a "smooth" a ride as possible.
4. The diet of astronauts prior to EVA operations should continue to preclude large food particles.
5. The "buddy system," or presence of a safety man, should be practiced for all EVA activities.
6. Astronauts should continue to be indoctrinated relative to the hazards of nausea within the confines of a space suit and enjoined to refrain from EVA activities when indisposed, regardless of mission priorities, unless required by an emergency condition.
7. Suit design progress should evolve in the following directions:
 - a. Provide increased astronaut mobility.
 - b. Incorporate redundant features to preclude catastrophic failure of any suit/PLSS element.
 - c. Include a positive collection method including a debris/vomit trap or bag.
 - d. Investigate the feasibility of including a backup system within the suit or PLSS.
 - e. Provide means to open the face mask to render aid.
 - f. Provide higher suit pressures to eliminate need for denitrogenization.
 - g. Provide integrated suit-backpack design.

HAZARD STUDY 36

RADIOLOGICAL ASPECTS OF NUCLEAR FLIGHT VEHICLE OPERATIONS

INTRODUCTION

The utilization of a reusable nuclear flight vehicle as the basic prime transport vehicle for lunar logistics shuttle service is being considered in two of the alternate advanced program plan study approaches currently being evaluated by the NASA (Ref. 1 and 2).

The nuclear flight vehicle as currently conceived is essentially a cryogenic monopropellant propulsion system. Propulsive thrust is provided by a rocket engine, designated as the NERVA engine system, which derives its thermal energy from a flight-operable nuclear reactor. The cryogenic monopropellant fluid is liquid hydrogen stored at a low pressure in the insulated stage tankage. The fluid is converted to gaseous hydrogen in the NERVA engine at pressures and temperatures sufficient to develop the required thrust at a reasonably high specific impulse.

The simple significant characteristic of the nuclear rocket engine which presents the greatest hazard to man and creates the largest amount of difficulty in the use of the nuclear vehicle is the intense radiation field associated with engine operation. Once activated the engine becomes intensely radioactive and remains so until the fission process has been shut down. Following shut-down the numerous species of fission products generated in the nuclear fuel decay (at various rates) causing a dropoff in radiation intensity with time. This process is amply described elsewhere in classical texts and literature (Ref. 3). The concern of this study area analysis is the assessment of the radiological effects occasioned by man's repetitive exposure to a nuclear flight vehicle in the lunar operations environment.

Basic radiological data developed in this Hazard Study is based on radiation source data presented in Supplemental Data Report No. 1, presented in Appendix E (Ref. 4). This reference contains several figures which should be considered a part of this Hazard Study.

ASSUMPTIONS

1. The nuclear vehicle considered, for purposes of this study, is a reusable nuclear shuttle (RNS) as generally defined and described in the Reference 5 documentation. The RNS missions and lunar shuttle duty definitions are taken as given in References 2 and 6.
2. The nuclear rocket engine considered is the NERVA engine rated at 1575 Mw thermal power and 75,000 pounds thrust. The nominal specific impulse is taken to be 825 seconds.
3. The study assumes that an orbiting lunar station (OLS) is operational and manned in a 60 nm polar orbit. It is further assumed that on-going program events such as surface activities, etc. are in progress. An active model is assumed to permit an examination of the widest spectrum of possible interfaces with the radiation exposure hazards.

The normal operation of a nuclear prime transport vehicle (N-PTV) in the performance of its mission functions in the lunar vicinity could potentially result in the exposure of lunar exploration personnel to measurable and possibly significant radiation levels, under certain operational circumstances. The operational events leading to such exposure encompass practically the entire N-PTV operational sequence from lunar approach through lunar departure. Additionally, any non-nominal operations on the part of the N-PTV tend to enhance the potential for significant personnel radiation exposure.

For analytical convenience, the N-PTV operational events considered to be significant hazard generators are treated in the following order:

1. N-PTV Lunar Orbit Insertion
2. N-PTV Lunar Orbit Residence
3. N-PTV Lunar Orbit Departure
4. N-PTV NERVA Engine Exhaust Plume
5. N-PTV Off-Nominal Performance

THE MAJOR HAZARDS

The significant major hazards generated from nominal and non-nominal nuclear prime transport vehicle operation in and around the lunar vicinity may be stated as follows:

1. The potential exposure of lunar exploration personnel to excessive amounts of nuclear radiation.
2. The potential contamination of lunar program elements, personnel and exploration area with radioactive particles or debris material.

ANALYSIS OF THE MAJOR HAZARDS

The analysis of the major significant hazards for this study area can best be accomplished through a systematic examination of the interface between the lunar exploration personnel activities and the nuclear prime transport vehicle operational event sequences as it proceeds through a typical logistics mission. Consequently, the hazards description and hazards effects aspects of the analysis will be treated within each of the hazards-generating-N-PTV-operational-event discussions which follow.

1. Nuclear-PTV Lunar Orbit Insertion:

The nuclear prime transport vehicle (N-PTV) upon lunar arrival is required only to inject into the reference orbit in the near vicinity of the orbiting lunar station (OLS). Payload transfers to and from the N-PTV will be conducted by manned tug vehicles. N-PTV coplanar lunar arrival opportunities occur twice each lunar month although normal logistics trip frequency would probably not exceed one every 54.6 days.

The Radiation Source:

For the arriving N-PTV, the most severe radiation environment will exist during the period in which the NERVA engine is operating, when both neutron and gamma radiation will be present. The intensity will depend on the engine/reactor power level, distance from the source, and intervening mass such as engine shielding or components. From Figure 1 of Ref. 4 it can be seen that significant dose rates may be encountered hundreds of miles away in the vacuum of space during periods of full power (1575 mw) operation.

The radiation environment about the N-PTV, during engine operation may be inferred from data presented in Figure 2 of Ref. 4 which illustrates the neutron and gamma radiation dose rate to a receptor for a separation distance of 100 ft. The sharp reduction in dose rate in the forward sector of the vehicle (0° - 15°) is related to the nuclear engine internal shield configuration. Distance effects can be extrapolated using the inverse square relationship of dose to distance.

When the engine is shut down and the source of neutrons eliminated, the radiation environment is considerably diminished, consisting primarily of gamma radiation due to fission product decay in the reactor core. Unlike the operating dose rate, which can be considered constant during periods of constant power operation, the post operational fission product source term is decaying with time after shutdown as well as distance and view angle. Figure 3 of Ref. 4 presents the fission product gamma dose rate versus distance from the unshielded NERVA engine following shutdown in lunar orbit. The data are plotted for a wide range of time-after-shutdown values. Figure 4 of Ref. 4 presents the shut down gamma dose - time profile for a 100 m separation distance and 90° view angle. The curve illustrates the dominant influence of the decaying shorter half-life fission products. The dose rate decreases by 3 orders of magnitude in 30 hours.

The LOI Exposure Hazard and Hazard Effects:a. Orbital Hazard and Effects

The integrated neutron and gamma dose levels which would be received by personnel at the orbiting lunar station (OLS) during the nuclear prime transport vehicle (N-PTV) lunar orbit insertion (LOI) has been evaluated in Ref. 4 for two normal insertion conditions; (1) final insertion at 10 km ahead of the OLS and (2) 10 km behind the OLS.

During the NERVA engine LOI burn the separation distance (N-PTV to OLS) and view angle for both conditions are virtually the same. The total radiation dose delivered to the OLS during the period from startup to shutdown was computed to be 0.194 mRem, of which 0.144 mRem was attributable to neutrons and 0.050 mRem to gamma radiation.

Almost coincident with engine shutdown the view angle becomes less than 15° for both conditions and remains so during most of the normal cool-down insertion. Thus, even though the N-PTV - OLS distance is diminishing, the protection provided by the engine internal shield effectively eliminates any radiation problem at the OLS. The variations in separation distance and view angle for the case in which final LOI occurs 10 Km behind the OLS are shown in Figure 10 of Ref. 4. The view angle for the alternate case is also shown in the same figure.

For N-PTV arrival 10 Km behind the OLS a total fission product gamma dose of 7.03 mRem, roughly 36 times the dose received during the LOI burn, will be received at the OLS. Most of this dose will be delivered during the time interval from about 38,000 to 39,000 seconds when the N-PTV is making a close passage with the OLS and the view angle is in the 60° to 140° range.

For the alternate N-PTV arrival condition, 10 Km ahead of the OLS, the N-PTV would always remain oriented such that the OLS is within the engine shield cone, effectively eliminating any measurable dose at the OLS.

Thus for nominal (by-the-book) N-PTV lunar orbit insertion maneuvers the expected exposure of personnel in the OLS would range from 0.2 mRem up to 7.0 mRem for the conditions evaluated in Ref. 4.

b. Lunar Surface Hazard and Effects

Radiation exposure to lunar exploration personnel or installation on the lunar surface along the incoming trajectory trace could occur during periods of nuclear engine operation for the lunar arrival of the N-PTV.

The most severe arrival situation would involve a single burn LOI maneuver in which a minimum recovery of aftercooling impulse was planned. This type insertion would result in the lowest altitude during the burn. The situation is represented pictorially in Figure 13 of Ref. 4. The N-PTV altitude at the beginning of steady-state operation is about 85 nm. Neutron and gamma doses delivered to various positions along the surface track were evaluated using the separation distance and view angle data given in Ref. 4. The total neutron and gamma dose received along the ground track number a maximum of about 26.5 mRem at position 3 vertically below the N-PTV at shutdown as shown in Figure 16 of Ref. 4. For a normal LOI approach with engine start up at an altitude of 125 nm the surface dose at the reference ground track position would decrease to one-half or one-third of the low altitude insertion value. A further discussion of this exposure problem will be found in Ref. 4.

2. Nuclear PTV Lunar Orbit Residence

On arriving at the moon the nuclear PTV will be divested of its inbound payload by lunar tugs or by using propulsion units in the payload itself. Sometime prior to departure, an Earth-return payload will be delivered to the N-PTV and docked to it. At all other times, the N-PTV will simply stand by in orbit waiting either to receive a payload or for the desired TEI opportunity to occur. If the N-PTV is near other space elements, it can be commanded to maintain a "nose-on" attitude toward the particular element to preclude any dose to crews or equipment,

thus eliminating any accumulation of radiation dose during normal N-PTV standby operations. It would be parked during such standby periods sufficiently distant from the OLS to permit unrestricted arrivals and departures of lunar tugs or other vehicles.

Except for an event involving an N-PTV system malfunction, essentially no hazards would normally be associated with this standby period.

3. Nuclear PTV Lunar Orbit Departure Orbital Exposure Hazards and Effects

The lunar orbit departure operation may be accomplished by using a single burn or a 3-burn maneuver, depending on the amount of plane change required to satisfy the trans-Earth injection (TEI) conditions. During the 3-burn departure the second and third burns will occur at such high altitudes that no effective dose will be received at the OLS.

The neutron and gamma radiation dose received at the OLS was evaluated (Ref. 4) for three departure startup conditions:

N-PTV at 10 Km Behind OLS

N-PTV at 10 Km Ahead of OLS

N-PTV at 20 nm Ahead of OLS

The integrated neutron and gamma radiation dose at the OLS for the three conditions were found to be:

<u>Position at Startup</u>	<u>Neutron Dose</u>	<u>Gamma Dose</u>
10 Km behind OLS	42.9 Rem	5.41 Rem
10 Km ahead of OLS	2.52 Rem	.139 Rem
20 nm ahead of OLS	.266 Rem	.015 Rem

The high dose for the case where startup occurs 10 Km behind the OLS results from the very close OLS passage (about 0.29 nm) during the engine operating period.

The high neutron dose for startup behind the OLS is eliminated if the initial distance is increased to about 30 nm, however, a close OLS

passage when fission product gamma rates are near maximum is still required. The risk of collision during the flyby represents another undesirable hazard.

The analyses (Ref. 4) support the **conclusion** that if startup near the OLS was required, a position ahead of it in orbit would be favored. A distance of at least 20 nm would be desirable. However, since the N-PTV requires no direct OLS support for the TEI maneuver a more desirable condition for startup would be with the N-PTV beyond the lunar horizon (about 680 nm for 60 nm orbit altitudes) such that the engine burn could not be seen at the OLS and none of the low altitude operation would occur near the OLS.

Surface Exposure Hazards and Effects

The most severe dose to the surface would probably occur for a single burn lunar departure with the N-PTV carrying maximum payload. Burn times of 300 to 400 sec. would be required most of which would occur at or near 60 nm altitude. The picture would be similar to the low altitude arrival with the exception that altitudes and relative velocities during the full-power interval would be lower, suggesting higher peak doses perhaps on the order of 50 mRem. While the resulting conditions on the surface should not be considered as indicative of a major problem, they should be carefully considered in planning surface activities if nuclear lunar shuttles are employed.

If any event surface doses from the nominal TEI burns would normally cause little concern for ground positions. However, if experiments with sensitive scientific measurement instruments were involved it may be necessary to provide some form of protection for those systems if they are to be situated in locations which could be directly beneath the N-PTV during periods of full-power operation.

4. Effect of NERVA Exhaust Plume on Orbiting Lunar Elements

During nuclear engine operation fission products can be ejected from the core either in particulate matter produced by corrosion of the fuel elements or as gaseous material diffusing through the fuel matrix. Since these fission products will be carried along in the exhaust, they could theoretically represent a hazard to systems such as the OLS or Lunar Tug which subsequently pass through the expanded exhaust plume.

A potential hazard to crewmen could possibly arise from a situation in which radioactive particulate matter were to be captured by the exterior surface of the OLS or other vehicle system. Subsequent EVA activities involving contact with the contaminated surfaces could result in a transfer of particles to the crewman's space suit or equipment and a potential direct skin contact or ingestion if the suit were handled after return to the spacecraft cabin. While a theoretical exposure route can be postulated, the potential for significant exposures is considered remote.

However, the possibility of radioactive particulate matter being introduced into the OLS or Tug closed life support system is one that must be considered and the consequences defined. For example, a catastrophic failure of the N-PTV engine system, such as loss of coolant to the engine causing destructive disassembly of the reactor could result in hazardous conditions at or near the OLS or other space elements. Depending on the location and concentration of the radioactive debris it is conceivable that manned activities at the OLS might have to be restricted or even discontinued until sufficient dispersement of the debris had taken place.

5. Off-Nominal N-PTV Operations and Their Hazard Potential

Some consideration should be given to the possibility of the N-PTV operating in an off-nominal manner and the impact such operations might have on the safety of the N-PTV or other orbiting space elements. For convenience off-optimum operations will be constrained to those

operations which result from human error or system malfunctions which do not result in mission abort. Three conditions were considered which fall into this class; (1) lunar approach guidance errors which cause low altitude LOI burn and/or operation close to the OLS, (2) guidance errors during the pulse cooling orbit insertion which could threaten the OLS with collision or close passage radiation exposure and (3) reductions in thrust at LOI which could alter burn duration and location relative to the OLS with final orbit insertion in other than the intended orbit.

Approach Guidance Errors

Approach asymptote errors would require an adjustment in the scheduled full-power engine operation at LOI and if the error was on the low altitude side, could result in performing the LOI burn close enough to the OLS to be of concern. Off-nominal approaches might be discovered too late to correct, but would be known far enough in advance to permit evaluation of the potential hazard which could result if insertion into the planned orbit was attempted. In the event an unacceptable hazard was predicted, injection into the planned orbit would be abandoned. A delayed LOI burn could be substituted, providing improved separation and view angle, injecting the N-PTV into elliptical orbit with later transfer to the OLS orbit. In this manner, radiation hazard to the OLS could be avoided although a performance penalty for the Earth-return leg would be encountered.

Guidance Errors During Pulse Cooling LOI

Guidance errors during the cooldown orbit insertion phase are probably the most likely area where off-nominal operations are apt to be encountered. Such errors could accidentally place the N-PTV in an orbit which could cause a collision or very close passage with the OLS. Preventing a catastrophic event of this type will require frequent updating of the N-PTV orbital parameters to insure prompt discovery of such a condition. Effect of close passage can be minimized by maintaining a nose-on attitude of the N-PTV during the period of concern.

Reductions in Thrust During LOI Burn

Reduction in thrust may be encountered during the main lunar orbit insertion burn due to malfunctions in either stage or engine systems. If the situation were unanticipated (no prior warning that full thrust could not be achieved), insertion into the planned orbit in a single burn could not be accomplished. Instead the reduced thrust arrival burn would brake the N-PTV into elliptical orbit. Near apocenter an idle mode NERVA burn could be used to reduce the pericenter altitude to 60 nm and finally a third burn near pericenter would be required to circularize the orbit. Additional phasing of the N-PTV in circular orbit might be required after circularization unless the elliptical orbit period was carefully synchronized with the OLS (Ref 4).

Alternate Corrective Measures

Preventive measures:

- a. The principal means of controlling N-PTV radiological hazard threats to lunar exploration crewmen will be the rigorous control of N-PTV spatial position in lunar orbit relative to the other operating elements of the lunar exploration program. The nuclear vehicle operations at and about the Moon must be so planned that N-PTV contributed radiation exposure to crewmen in orbit and on the surface does not significantly increase the radiation dose above that expected from natural (cosmic) radiation sources (see Hazard Study 31).

Remedial measures:

Not applicable to this study area.

Escape/Rescue Requirements

The escape/rescue requirements are not specifically considered in this study area since the subject is primarily concerned with examining problem areas requiring future study. However, the requirements given in Hazard Study 31 may be considered to apply.

SOURCE DATA REFERENCES

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2. "MSC Integrated Program Plan Reference Schedule - High Budget Base Line", MSC/AMPO, May 18, 1970.
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4. "A Study to Evaluate Radiation Exposure to the Orbiting Lunar Station and Lunar Surface Related to Reuseable Nuclear Shuttle Operations", Supplemental Data Report No. 1, Appendix E, of this report.
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6. NASA - Project Description Document - Nuclear Stage, Vol. I, Project Definition, April 13, 1970, MSC/AMPO.

HAZARD STUDY 36
SUMMARY OF SAFETY GUIDELINE CANDIDATES

1. Consideration of "crew radiation-exposure accountability" must be included in the administrative procedures devised for lunar exploration mission planning. It must be possible to update each crewman's exposure record at least once each 24 hours.
2. Serious consideration shall be given to the implementation of a mission planning function which will thoroughly evaluate the "crew radiation exposure potential" for each phase and activity of the planned missions.
3. Specific lunar exploration crew safety studies shall be conducted which explore the radiation hazards to man associated with nuclear lunar shuttle trajectories for LOI and TEI maneuvers. Hazard-minimizing trajectories and orbits shall be selected for the N-PTV which prevent the best trade-off of performance and safety. The studies shall be conducted in the context of the intended logistics missions for which the N-PTV is scheduled.
4. Specific studies are required to identify and characterize the off-nominal performance conditions and situations which may occur in the employment of a nuclear prime transport vehicle in the lunar exploration program. The impact of the off-nominal performance situations in terms of radiological hazards of lunar exploration personnel is to be defined such that the development of suitable operational remedies is possible.

HAZARDS STUDY 37

HUMAN ERROR

INTRODUCTION

The potential hazards engendered by the unintentional or inadvertent departure from established plans or procedures is the subject of this study area. While the subject itself can be expanded to great length, this particular study will consider only the significant major hazards, deriving from human error, which have critical program implications.

Human performance failures chargeable to human error have been an area of study and concern by human factors groups for many years. Basically, the occurrence of such performance failures, which can be classed broadly as human error, appear to be relatable to unawareness, fatigue and/or distraction of attention. The classic phrase - "Pay attention to what you are doing" - uttered in many forms by concerned associates and mission controllers, is a universal reminder that human error is viewed by all as a distinct hazard of serious proportions. The extreme concern is warranted by more than ample evidence available in terms of documented consequences of error.

The significant hazards aspects of human error occurrence in the advanced lunar exploration program are of great interest in planning for the safety of personnel likely to be engaged in exploration activity.

ASSUMPTIONS

1. The lunar exploration personnel complement comprises a mixture of highly trained astronauts (pilots and station commander) and skilled scientists and engineers who will receive thorough astronaut training aimed at providing a full capability to function effectively in the lunar environment (Ref. 1). Because the complement of the lunar complex will be relatively small for several years after its initiation it is expected that

all personnel in the complex during those early years will be trained fully in the handling of all abnormal or emergency situations.

2. The critical and significant areas of concern are those operations involving the initiation, control and termination of all flight maneuvers and the execution of orbital or surface personnel activities where personnel loss could result from human error.

THE MAJOR HAZARDS

The major hazards identified are:

1. Judgment errors
2. Reaction errors

ANALYSIS OF IDENTIFIED HAZARDS

Effects of Hazard 1, Judgment Errors

Judgment errors perhaps constitute the most significant hazard within the human error classification. A basic reason for the emphasis upon computerized guidance and control stems from the fact that the decision time constraints involved in high velocity maneuvers are so short that there is literally no time for correcting a judgment error and still achieve a correct maneuver. Further, there are many instances where the human senses are negated by external physical phenomena such as light wash-out of visual cues, or dust clouds generated by plume impingement which give seriously degraded visibility below a 50 ft altitude (Ref 2). Under such circumstances judgment errors have a high probability of occurrence.

Typical consequences of judgment errors in lunar operations which can be critical or catastrophic in nature are:

- Docking: Closure velocity errors
 - Angular misalignment
- Landing: Reliance on visual cues instead of instrumentation data
- Ascent: Disregard of checklist sequence in prelift-off checkout and/or omission of critical checks.
- Orbital Operations: Disregard of approach restrictions established for:
 - a. Protection of station equipment
 - b. Crew protection from nuclear-PTV radiation field
 - c. Crew safety at propellant depot
 - d. Protection from collision in satellite orbit
- Disregard of warning instrumentation indicating:
 - a. Life support problem
 - b. Vehicle system operating parameter out-of-tolerance signal
- Disregard of procedures without prior approval
- Surface Operations: Authorizing or performing EVA without backup in a non-emergency situation
- Deviation from sortie plan without approval
- Disregard of procedures without prior approval
- Performing of unauthorized experiments
- Failure to notify associates and base of suspected hazardous condition or situation

Causative factors of primary importance in the generation of judgment errors in otherwise nominal situations involving well trained personnel are the following:

1. Fatigue induced errors - primarily resulting from a long and somewhat arduous series of demanding tasks such as might be encountered on an extended lunar surface sortie. Fatigue build-up even in well trained personnel can produce degradation of mental alertness.
2. Impaired Awareness - this condition may result from several causes including the excessive fatigue discussed above. Of more significance, however, is the fact that impaired awareness is a rapidly occurring manifestation of CO₂ buildup (or toxicity). It also results from the buildup of other gases which poison or cause oxygen starvation in the human organism. Thus a suited crewman, or crewmen in a small volume such as a cabin rover, could rather rapidly be subject to this condition if a failed detector system went unnoticed.

A further aspect of impaired awareness would be "unawareness" itself. This could arise from a failed or malfunctioning detector system (radar, radiation detector, I.R. device, etc) which left the crewmen completely unaware of an impending or approaching hazard.

Corrective Measures for Hazard 1

Preventive measures:

1. Flight operations shall require at least two crewmen at the flight station during all critical maneuvers such as docking, landing, ascent and orbit change burns. The second crewman shall monitor the checklist, monitor critical operating parameters, and assist the pilot in the execution of the maneuvers.
2. The buddy system shall be required for all activities where a crewman may be jeopardized by an equipment or environment induced or self-induced function failure.
3. A specific study is recommended to ascertain and define the most probable source of human error likely to be encountered in the operations, events, and activities of a lunar exploration program. The study should consider the define program elements involved and should consider defined mission

events, and activities in the logical sequential order in which they occur.

4. Specific work-rest ratio studies should be conducted to ascertain (by simulation and activity mockup) the total fatigue buildup characteristic of all planned lunar surface sorties and traverses.
5. Specific design and development effort is recommended in the region of toxic atmosphere detection to provide maximum assurance that the level of toxic contaminants in the life support equipment of any station compartment, tug crew compartment, suit, surface base or rover installation shall never be high enough to degrade crew awareness in their activities.
6. All primary sensors necessary to provide awareness data to the crew (approach radar, radiation detectors, I.R. detectors, etc) should be fail-operational for two levels of failure and fail safe for the third.

Remedial Measures:

Potential remedial measures for judgment errors can only be defined when the capabilities of the vehicles or specific activities considered are known in considerable detail. At this time meaningful remedies cannot be provided.

Escape/Rescue Requirements for Hazard 1

Judgment errors can produce requirements for both escape and rescue, however, in this study area neither will be specified since the study treats the general hazards or group of possibilities.

Effects of Hazard 2, Reaction Errors

Reaction error as a major hazard is in itself both a hazard and a hazard generator. Reaction error includes improper procedure, such as the inadvertent or accidental activation of a system via button pushing, switching, or bumping as well as the accidental misreading of gauges, dials and digital displays. Reaction error may result from haste, conditioned reflex, tactile

encumbrance (space suit gloves), or even lurching of the spacecraft due to unplanned motions or accelerations.

The effects of reaction errors may range from the simple nuisance of resetting a system to the generation of critical or even catastrophic hazards and their consequences.

Typical examples of the range are:

1. Inadvertent fuel cell feed cutoff requires reset, reactivation of feed, placing fuel cell "on-line", and an electrical readings check taking about 30 minutes.
2. Inadvertent activation of a large rover vehicle while other crewman is preparing to board vehicle causing personnel accident.
3. Accidental activation of "emergency" docking latch release while hatch door is unsecured. (Assumes "emergency" latch release overrides normal hatch release interlock.)

Corrective Measures for Hazard 2

Preventive Measures:

1. Human factors and engineering study of all system activation devices (buttons, switches, knobs and handles) should be performed to insure that such devices are protected, properly spaced, properly sequenced and interlocked, accessible, and placed according to sequential requirements. Specific attention must be given to devices which must be operated by suited crewmen in order to provide adequate hand grip and movement distance (Ref. 3). Crew preference should be considered in this respect to the greatest extent possible consistent with design constraints and system operational requirements.
2. Full size mockups of planned control stations should be provided for meticulous review and simulation exercises to permit evolution of final configurations having the least potential for reaction errors or for

inducing judgment errors. "The detection and elimination of potential sources of human error shall be an integral part of this activity." (Ref 4)

Remedial Measures:

Not applicable to this study for the same reasons given in Hazard 1.

Escape/Rescue Requirements for Hazard 2

Not applicable for same reasons as given in Hazard 1.

SOURCE DATA REFERENCES

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3. "Apollo 12 Mission Report," MSC-01855 Manned Spacecraft Center, Houston, Texas, March, 1970.
4. "An Introduction to the Assurance of Human Performance in Space Systems", NASA Sp-6506, dated 1968.

HAZARD STUDY 37
SUMMARY OF SAFETY GUIDELINE CANDIDATES

1. Lunar flight operations shall require two crewmen at the flight station during all critical flight maneuvers such as docking, landing, ascent, and orbit change burns. The second crewman shall function as a judgment error monitor and shall assist the pilot in the execution of the maneuvers as necessary.
2. A "buddy-system" mode of operation, or presence of a safety man shall be implemented for all hazardous activities where a crewman may be jeopardized by an equipment or environment induced or self-induced malfunction or mishap.
3. The probable sources of human error likely to be encountered in the expanded lunar exploration program should be identified. These sources should be considered in program element design refinement for safety enhancement. The effort should include as necessary, work-rest ratios, fatigue buildup, reaction error studies and such other human factors and engineering aspects as may be required to suppress the potential for human error to minimum levels.
4. Specific efforts are recommended to enlarge upon the use of simulators and full scale mockup equipments for the configuration evolution of program element control and work stations.

HAZARD STUDY 38

METEOROIDS

INTRODUCTION

Meteoroid strikes can cause damage ranging from surface abrasion to destruction of a space vehicle, depending on particle size and velocity. A thorough discussion of the meteoroid flux in the vicinity of the moon and commensurate particle sizes and velocities is given in Ref. (a). All three of the cited references deal with meteoroids from the point of view of the spacecraft designer and offer bases from which one can select protection against meteoroid penetration.

ASSUMPTIONS

1. The meteoroid flux, particle size, and particle density are as stated in Ref. (a) in the vicinity of the moon.
2. All other pertinent effects such as those due to shielding of the spacecraft by the moon, the presence of various meteoroid showers as a function of the yearly season, etc., are also as given in Ref. (b).

THE MAJOR HAZARDS

The major hazards identified are:

1. A meteoroid penetrates into the manned cabin of any lunar spacecraft in orbit or on the lunar surface leading to a vaporific flash and damage to subsystem hardware. In addition the crew is endangered by loss of oxygen by a continuing fire after the flash and by physical injury.
2. A meteoroid penetrates the suit of an EVA astronaut in orbit, on the lunar surface walking or in an open rover or flyer causing loss of atmosphere and possible injury.

ANALYSIS OF IDENTIFIED HAZARDS

Effects of Hazard 1, Meteoroid Penetration of Pressure Cabin

A vaporific flash is the result of very rapid oxidation of a meteoroid which has penetrated a cabin wall. Such a flash produces flame, a temperature and commensurate pressure increase which in turn yields damage to the contents of the cabin. Penetration is then followed by decompression and a severe temperature decrease. Pure oxygen atmospheres at an initial level to satisfy respiration needs for man - 3 psi - or greater - up to say, 5.5 psi - yield much more violent reactions than an atmosphere that contains a diluent such as nitrogen along with oxygen. The characteristics of the flash depend on the kinetic energy of the meteoroid at cabin penetration, the cabin atmospheric constituents, and the hardware in the cabin itself together with the crew. Because of their very high velocities - 20 to 30 km/sec are widely accepted averages - any meteoroid that penetrates a cabin wall presents a considerable danger to man and his supporting equipment. The fluxes of meteoroids have been well bounded for the smaller particles up to sizes of the order of a large grain of sand. The frequency of meteoroid strikes for larger particles -- where the danger really lies -- are much less well known.

Effects of vaporific flash in manned cabins cover a spectrum from superficially burned clothing and skin to third degree burns, lung searing and death.

The effects on man and his equipment will be, as discussed above, a strong function of the pressure and percent of oxygen in the cabin atmosphere.

Specific injuries and damage cannot be ascertained without providing a reasonably accurate scenario with respect to cabin volume, numbers of crew members present, clothing worn, atmospheric constituents and their partial pressures, materials in the cabin other than the crew, and the kinetic

energy of the meteoroid transmitted into heat. The potential hazard is, however, evident and the lunar crews must be protected against meteoroid penetration of their cabins or EVA suits.

Corrective Measures for Hazard 1

Preventive measures:

1. Meteoroid shields should be designed for all lunar spacecraft, bases, and vehicles that have manned cabins. Such designs should afford the protection required to meet acceptable risk probability criteria.
2. The atmospheres of manned cabins should preferably consist of 2 gas systems, oxygen with nitrogen as the diluent in order to suppress the fire-damage potential in the event of a meteoroid penetration.
3. Optics or such hardware as is critical in the support and protection of crew members should be protected from meteoroid damage through the use of iris-like shields during all times except when optics are in actual use. When feasible, optics shades should be provided to extend protection during the time the optics are being used.

Remedial measures:

1. Meteoroid strikes that have sufficient energy to penetrate a cabin wall but which do not cause a flash will, in any case, lead to depressurization phenomena. Consequently, a kit analogous to a tire repair kit should be evolved to permit quick repairs to such penetrations. Repair methods are discussed in Hazard Study 21.5.
2. Fire extinguishing equipment should be readily available. Such fluids as may be used in fire fighting equipment should be selected to have minimal deleterious effect on the environmental control system.
3. Equipment containing aids to combat burn injuries should be included in the medical supplies aboard all spacecraft and in the LSB. All should be trained in the treatment of burns.

Effects of Hazard 2, Meteoroid Penetration of Space Suit

A meteoroid strike and penetration of a suited man will have effects similar to those described for Hazard 1 except the hazard is likely to be much more severe. The pure oxygen atmosphere may react violently, the small volume of atmosphere in a suit can be lost more rapidly than in a larger cabin, backup devices are not so readily kept at hand, and a strike that penetrates a suit has reached the body of the occupant.

Corrective Measures for Hazard 2

Preventive Measures:

1. Practical preventive measures for meteoroid penetration of an EVA crewman's suit are not now available. Some protection can be afforded from the small meteoroids by designing outer garments to be penetration resistant, within practical weight limits, and by local shielding of critical hardware. The knowledge in Ref (a), (b), (c) should be applied to ascertain the safety of and need for design changes in EVA suits.

Remedial Measures:

1. Remedial measures will be futile for any but minor penetrations of an EVA crewman's suit. Where a penetration has resulted in a slow leak, with little or no injury to the man, temporary repair of the opening with a patch or donning of an emergency pressure garment may suffice until a safe haven can be reached or a rescue accomplished. In either event, use of the buddy system on EVA should reduce the hazard by providing immediate assistance.

Escape/Rescue Requirements

Meteoroid punctures may generate a requirement to escape to a backup pressurized compartment, second vehicle, or other safe haven. If a safe haven cannot be reached through escape, rescue will be required.

RECOMMENDATION FOR FURTHER STUDY

There is a large uncertainty concerning the frequency of the larger sizes of meteoroids in the vicinity of the Moon. It is recommended that additional studies be initiated to decrease that uncertainty. Interest lies in sizes of about 1 gram and larger for both stony and nickel/iron meteoroids.

DATA SOURCE REFERENCES

- (a) Meteoroid Environment Model - 1969 (Near Earth to Lunar Surface), (NASA Space Vehicle Design Criteria, Environment), NASA SP-8013, March, 1969.
- (b) Protection Against Meteoroids (NASA Space Vehicle Design Criteria, Structures), NASA SP-80XX, May 1970 - Preliminary - To be published as a NASA monograph.
- (c) Space Environment Criteria Guidelines for use in Space Vehicle Development (1969 Revision), D. K. Weidner, Editor, Aero-Astroynamics Laboratory, NASA TMX - 53957, October 17, 1969; NASA/MSFC.

HAZARD STUDY 38
SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. Every effort shall be made to provide a two-gas atmosphere in spacecraft cabins, using a diluent such as nitrogen in order to suppress vaporific flash during meteoroid penetrations.
2. All critical hardware directly exposed to the space environment shall have protection against meteoroids as required to meet acceptable risk probability criteria.
3. Kits shall be devised for the quick repair of small holes in manned cabins caused by meteoroid punctures.
4. Lunar bases and spacecraft shall be designed, where feasible, to have two or more compartments, each capable of maintaining the cabin atmosphere which supports the crew life functions.
5. All manned cabins shall carry a spacesuit for each crew member aboard.
6. All optics in hardware critical to support, protection, and survival of crew members shall have protective shields, such as iris-type closures, when not in use.
7. The buddy system shall be used for all EVA operations.
8. All spacecraft, lunar surface base, and other vehicles in the lunar complex shall carry medical equipment for the treatment of burns. All crew members shall be trained in the treatment of burns.
9. Make maximum use of nonflammable materials in pressure suits and materials.

HAZARD STUDY 39

CREW INGRESS/EGRESS PROBLEMS ASSOCIATED WITH DYSBARISM

INTRODUCTION

There are well established hazards to the astronaut associated with rapid transitions from currently postulated lunar orbital base or advanced lunar shelter cabin atmospheres to the space suit environment. This section will discuss the hazards associated with dysbarism and the measures available for coping with this potential problem.

ASSUMPTIONS

This study deals with transitional effects associated with changes in environmental atmosphere/pressure. It is important to make certain assumptions regarding the characteristics of advanced lunar vehicles, shelters, and orbital bases projected for the 1980-90 period. The following table summarizes current thinking in this regard:

Habitable Enclosure	Atmosphere Composition	Pressure
Orbiting Lunar Station (OLS)	O_2N_2	14.7 psi
Advanced Large Cabin Rover	O_2	5 psi
Lunar Surface Base	O_2N_2	14.7 psi*
Space Tug	O_2N_2	14.7 psi
Current Space Suits	O_2	3.5 psi

* Ref. (7), Page 168, suggests maximum of 7.5 psia, composition not given.

THE MAJOR HAZARD

Classified and clinically significant dysbarism is a hazard that could result from the following astronaut ingress/egress transitions:

- OLS to EVA Space Suit
- Space Tug Lunar Shelter to Lunar EVA operations
- Lunar Surface Base to Lunar EVA
- Lunar Surface Base to Lunar Surface Rover

ANALYSIS OF IDENTIFIED HAZARDS

Description and Effects of Dysbarism

Dysbarism consists of those disturbances in the body which result from the existence of a pressure differential in the body between the total ambient barometric pressure and the total pressures of dissolved and free gases within the body tissues, fluids and cavities. Hypobarism refers to disturbances in the body resulting from an excess of the gas pressure within the body fluids, tissues or cavities over the ambient gas pressure. This form of dysbarism might occur, for example, when the astronaut transitions improperly from the Lunar Base O_2N_2 14.7 psi environment to the space suit 3.5 psi pure oxygen environment. From Ref. 1, examples of Hypobaric disturbances include:

1. Bends - deep, boring pains in the joints, bones or muscles of extremities including the hip and shoulder caused by the evolution of gas from solution resulting in bubble formation.
2. Chokes - sense of constriction or tightness in the chest or oppression in the chest with pain, dry cough, difficulty in breathing with a sense of suffocation and apprehension due probably to irritation of the pulmonary tissues when gas emboli cause obstruction of pulmonary arterioles and capillaries.
3. Central Nervous System Symptoms - The incidence of central nervous system symptoms is relatively small and very variable in type and severity. These symptoms include one or more of the following:

disturbances of equilibrium and coordination, disturbances of function of large sensory or motor tracts, disturbances of consciousness and cortical function, e.g., hallucinosis, disturbances suggesting of increased cranial pressure, e.g., headache and painful eye movements; nausea; and blood pressure depression.

4. Skin Disturbances - cutaneous discolorations, rashes, and itching.
5. Abdominal Symptoms - "gas pains" and bloating

Hyperbaric disturbances result from an excess of the ambient gas pressure over that within the body fluids, tissues and cavities. This form of dysbarism might occur subsequent to a transition from a space suit environment to a higher pressure shelter or orbital station environment. Symptoms associated with hyperbarism are:

1. Barotalgia - ear pain caused by blockage of pharyngeal orifice of the eustachian tube preventing the entrance of air from the oral cavity into the middle ear and causing a differential pressure across the tympanic membrane.
2. Barosinusitis - pain in the sinuses due to expansion of mucus membranes and the creation of unequal pressures in the sinus cavities.
3. Barodontalgia - pain in the teeth ranging from dull ache to sharp and severe pain attributable to changes in barometric pressures.

Individuals subject to hyperbaric disturbances may largely be eliminated through crew selection procedures. However, long exposure to space environment could conceivably susceptibility to these effects.

Corrective Measures

Problems associated with dysbarism can be avoided by taking two alternate courses:

1. All habitable elements of the lunar surface and orbital system can be designed to accommodate the same pressures and atmospheres or
2. provide adequate transitional means to allow denitrogenation and accommodation of the astronaut to new pressure/gas environments.

The first approach; namely that of making all habitable system elements compatible, offers major problems in regard to space suit design. If the space suit design could be modified to allow performance of EVA at standard atmosphere pressure, thereby eliminating transitions from higher shelter or orbital station atmosphere pressures, the problems associated with dysbarism would largely be eliminated. Similarly, the large cabin rovers could be designed for a normal Earth ambient atmosphere.

Impediments to space suit operation at higher total pressures (14.7 vs. 3.5 psi) consist of the following undesirable suit characteristics:

- a) Greater suit strength required to sustain higher pressures
- b) Higher suit leakage rates would be expected
- c) Reduced astronaut workloads would be anticipated in performing EVA tasks.

While present "soft" suit concepts do not lend themselves to operation at greatly increased total pressures (going from 3.5 to 14.7 psi), the "hard" suit concept could, in all probability, be developed to accommodate these higher pressures and a mixed gas system. A Litton Industries progress report dated September 1966 states:

The RX series of space suits is designed to accommodate normal operation at 5 psi with either single or mixed gas atmospheres. Implications on performance of RX suits designed for a mixed gas system are:

1. The mobility of the suit (i.e., joint range and torque) would not require major redesign of any components if pressure were in the 7 to 7.5 psi regime. A 14.7 psi arm/glove has been developed by Litton for the Lunar Receiving Laboratory.
2. Weight of the suit would not materially be affected if the suit were operated at 7 to 7.5 psi. If the suit were made to operate at 14.7 psi an additional weight penalty of 20 lbs. could be expected.
3. Life support would not be unduly complicated by the addition of an inert gas since the low leak rate characteristics of this suit would require that only oxygen make-up supply be carried in the life support system.

The second alternative approach to coping with the dysbarism problem involves denitrogenation of EVA personnel prior to EVA sorties. Denitrogenation consists of breathing increased percentages of oxygen for extensive periods prior to transitioning from the O_2N_2 , 14 psi to the 3.5 psi, pure O_2 environment. The elimination of nitrogen from the body prior to exposure to reduced pressures and before it can form bubbles should prevent the symptoms. To effect a reduction of nitrogen in the body, high concentrations of oxygen can be inspired for varying intervals of time.

The rate at which nitrogen is eliminated from the body has been studied by a number of investigators. About one-half of the body nitrogen is contained in the fatty tissues of an individual whose fat content is 15 to 20% of his body weight. During decompressions of short duration, the body fat may act as a reservoir to protect the body against the sudden release of nitrogen and bubble formation. Typical nitrogen desaturation curves reveal a number of important facts: (1) the weight of nitrogen dissolved in the body varies directly with the partial pressure of N_2 in the inspired air; (2) the rate of nitrogen elimination in terms of volume per unit time is a direct function of the gradient of nitrogen tension (difference in partial pressures) between the outside and inside of the body. This means that if the nitrogen tension of the inspired air were reduced to zero, the rate of its elimination would be twice as fast as it would be if its tension were only reduced 50%. (Ref. 1)

There are other features of denitrogenation which are of interest. The measurements which have been made show that denitrogenation is most rapid at the beginning and then reaches a zero rate after about 6 to 8 hours; 50% denitrogenation is accomplished in about 30 minutes.

It is of interest that the rate of nitrogen elimination differs significantly between individuals and in the same individual from day to day, and that the subjects with a high rate of nitrogen elimination are generally more resistant to dysbarism than are other subjects.

It has been found that approximately 4 hours of inhalation of 100% oxygen is necessary to completely protect the more susceptible individuals who were expected to exercise at 35,000 ft (3.5 psi). One or two hours of oxygen inhalation offered more complete protection from bends than from chokes. Exercise, along with pre-mission denitrogenation might give accelerated elimination of nitrogen; however, this benefit could be overshadowed by the disadvantage of resulting fatigue.

Tests have shown that protection against the bends during denitrogenation is completely effective so long as 100% oxygen is being used at a pressure of 6.8 psi or greater.

The conclusion, based on this investigation, seems to be to recommend a minimum denitrogenation period of 3 hours and preferably 4 hours prior to EVA in addition to selection of a crew relatively immune to dysbarism.

The operational and design implications of denitrogenation or preoxygenation requirements are clear:

1. Orbital Lunar Station - The airlock should allow provisions for 2-4 hours of uninterrupted preoxygenation prior to suit donning and EVA activities. This airlock must be large enough to accommodate simultaneous occupancy and suit donning of all EVA personnel including a standby emergency rescue astronaut.
2. Space Tug - The Space Tug must be compatible with both the orbiting lunar station (OLS) and lunar surface operations. When docked to the OLS, the tug should be at 14.7 psi O_2N_2 for transfer of personnel. When transitioning from lunar orbit to lunar surface, personnel who are to go EVA on the lunar surface should be denitrogenating. This denitrogenation can occur within the space tug environmental system can be designed to transition from a two gas O_2N_2 15 psi system to a pure O_2 3.5 psi system. Time from lunar orbit to lunar surface will normally range from 3.5 to 7 hours allowing for phasing and plane changes. This time is sufficient to allow denitrogenation for EVA operations upon landing.

3. Lunar Shelters - operated at O_2N_2 , 14.7 psi will similarly require airlocks which allow denitrogenation capability, and lunar activity schedules should provide for preoxygenation times of 2 to 4 hours preceding EVA. Standby rescue personnel would have to be in a pre-oxygenated and suited condition while other crewmen are engaged in EVA operations.
4. Large Cabin Rover - If these vehicles are designed for a 5 psi, pure oxygen environment, transition to the suit environment offers no problems beyond the several minutes required for pressure equalization to the 3.5 psi, O_2 suit environment.

In addition to denitrogenation as a technique for avoiding dysbarism effects, other measures which should be taken are:

1. Selection of astronaut personnel who are relatively immune or less susceptible to pressure transition effects. Altitude chamber exercises are useful in classifying personnel with regard to their susceptibility to dysbarism and hypoxia.
2. Drug therapy as a means of preventing or increasing tolerance for bends symptoms should continue to be studied.
3. Extensive training of astronaut candidates in the recognition of dysbarism symptoms.

Escape/Rescue Requirements

The first symptoms of pressure change that might appear are barotalgia, barosinus or abdominal bloating. These symptoms would probably appear while the astronaut was in the airlock preoxygenating and would prevent him from going EVA.

The onset of bends, chokes and central nervous system phenomena could appear while the astronaut was engaged in lunar orbit or lunar surface EVA activities. The astronaut should be trained to recognize these symptoms of dysbarism and return to the shelter or orbital station, either unassisted or, depending on the severity of the symptoms, assisted by a "buddy" astronaut. The possibility of dysbarism effects argues strongly for the "buddy system" for EVA opera-

tions since it is unlikely that both astronauts are similarly and simultaneously incapacitated if normal preoxygenation precautions have been observed.

For severe cases of bends and other dysbarism symptoms, compression therapy is the treatment required. Studies by the USAF School of Aerospace Medicine Decompression Sickness Management Team indicate that compression in hyperbaric treatment chamber is required. A pressure bag has been designed to afford relief of bends in aircraft. This bag was designed for combat situations where a crew member might develop severe symptoms during conditions where descent of the aircraft to lower attitude would be dangerous. The affected individual is placed in the pressure bag which is inflated by an air compressor. The bag is equipped with an oxygen regulator, headset and electrically heated suit circuit.

Some modification of this approach for space application may be required for treatment of bends. It may also be possible to overpressurize the airlock compartment of the shelter or lunar base as a treatment technique. This would incur obvious weight and structural penalties to support the increased pressure.

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6. Middleton, R. H., Bends and Denitrogenation in High-Altitude Flight Operations, Aero Medical Laboratory, Wright Air Development Center, WADC Tech. Report 58-625, March 1959.
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HAZARD STUDY 39
SUMMARY OF SAFETY GUIDELINES CANDIDATES

1. The "buddy" system, or presence of a safety man, should be practiced during EVA activities so that an astronaut who is incapacitated from dysbarism effects or other illness, can be guided back to a safe shelter.
2. Adequate provisions for simultaneously denitrogenating EVA personnel should be provided in the OLS, the Space Tug and the Lunar Base.
3. Crew activity schedules should allow sufficient time for adequate denitrogenation when a transition must be made from a higher pressure, 2 gas cabin to lower pressure pure oxygen suit environment.
4. Astronaut selection criteria should continue to stress relative immunity from the symptoms of dysbarism.
5. Astronaut training programs should continue to indoctrinate candidates on the symptomology of dysbarism.
6. Drug therapy as a means for preventing or increasing tolerance for bends symptoms should be investigated.
7. Compression therapy techniques and devices, such as the pressure bag, should be developed for space applications to treat dysbarism symptoms.

Section 3

SPECIAL TRADEOFFS

3.1 THE LUNAR COMPLEX WITH AND WITHOUT AN ORBITING LUNAR STATION

FUNCTIONS OF A LUNAR SPACE STATION

The lunar space station acts as a control center for operations both in lunar orbit and on the lunar surface. A certain amount of scientific investigation will be carried out aboard the station; viz., lunar mapping, astronomical observations.

The station will act as control center for missions to the surface and will provide data to the landers as required. The station will act as a communications relay between lunar landers, the LSB, and the Earth.

If a separate propellant depot is established in lunar orbit it will be under the command of the station. The depot and all other members of the lunar complex will be tracked and essential parameters displayed (and acted upon if necessary) via telemetry.

Besides operating an astronomical observatory in lunar orbit, all surface sites of interest will be photographed by the station crew as part of the planning for scientific investigation of such sites. Data derived from various lunar experiments will be processed aboard the station.

The station would provide a safe haven for crew members rescued via a tug from orbit or from the surface. This assumes great importance if medical treatment is needed.

THE LUNAR COMPLEX WITH A LUNAR SPACE STATION

No hazards of any consequence are recognized that are due to the presence of a lunar space station in the lunar complex.

THE LUNAR COMPLEX WITHOUT A LUNAR SPACE STATION

A number of hazards are apparent if no lunar space station exists in the lunar complex. The hazards assume greater importance when lunar surface exploration is initiated since at that time only the tug exists as a haven

and medical aid, for example, is limited to whatever is aboard the tug. Other treatment then requires a return to Earth orbit.

1. At lunar complex initiation, neither a space station nor a lunar surface base are available as a safe haven in the events of injury, need for medical treatment, or following rescue.
2. No orbital site will exist where a fully (propellant) loaded tug will be docked, constantly monitored and readily available for rescue, undeterred by involvement in other tasks.
3. It would be difficult to monitor a propellant depot in orbit without the station, and its location and status would only be known on an intermittent basis. No station crew would be available to aid in propellant exchange between the depot and another spacecraft. This task becomes more hazardous when such exchanges are instituted without the experience and aid of a station crew who are totally familiar with the depot.
4. Since the proposed Integrated Program Plan (IPP) calls for non-nuclear powered prime transport vehicles to dock at the station when delivering personnel to the lunar complex, the lack of a station leaves newly arrived personnel to fend for themselves in getting down to the surface without briefings and other familiarizing aids. Moreover, there is no haven where they may prepare themselves for the long sortie on the lunar surface; therefore their stamina will be imposed upon to a considerable degree.
5. Operations on the back side of the Moon would be hazardous, if not entirely forbidden, since only indirect communications could be conducted using an L_2 libration point comsat. Initiating rescue from the Earth facing side of the Moon to the farside without a space station would be very time consuming and hence would subject the farside crew to whatever hazard befell them for extended intervals. This is certain to increase the severity of many situations; in some cases crew members would be lost because of the lack of quick rescue capability.

6. Optical-visual inspection of sites intended for scientific investigation would also have to be accomplished using the tug and such activity for any one site would either be time limited or would require relinquishing the tug from other tasks for long periods. These kinds of orbital tug activity in essence add the requirement for another tug in the lunar complex. Alternative surface based methods of choosing sites for investigation would not be as accurate and thus imply the hazard of uncertainty about the nature of the site. This in turn would complicate rescue should that need arise.
7. In the absence of a lunar orbital terminus, all deliveries of cargo and crew would have to be made from a prime transport vehicle (PTV) in lunar orbit directly to the surface. In such a case the PTV would have to bring a tug to lunar orbit to complete surface delivery or a tug parked on the surface would have to ascend to lunar orbit, dock to the PTV, transfer cargo and return to the surface base. Any problems or hazards encountered during orbital transfer activity would have to be resolved by the tug crew. No station would exist to offer any kind of aid should it be needed. A tug that had to abort a descent to the surface would face a great hazard in that no safe haven would exist after the abort. Rescue would have to be conducted and initiated with a tug on the surface or from Earth orbit. This type of procedure would increase required ascents and descents and thereby increase exposure to potential hazards.
8. The lack of a space station in lunar orbit would be to the disadvantage of arriving PTVs, since with the station injection into lunar orbit could be made accurately using station beacons and other guidance aids as desired. Without the station the PTV becomes entirely dependent on its onboard capability. Should an arriving PTV develop any problems on arrival or should lunar injection be unsatisfactory (or fail completely), the hazard of crew isolation arises and rescue would face the handicap of being initiated from the lunar surface or Earth Orbit. Such a PTV-involved rescue could leave the crew and tug stranded in orbit for long periods. Because of the large expenditure of propellant for the rescue, the tug would need a source of propellant for return to the lunar sur-

face. Without a station, such a source would have to be on the lunar surface where the rescue mission is initiated. Transfer of propellant to the orbital tug would be complicated under such conditions.

The advantages of having a station in lunar orbit together with obviating of the hazards discussed above by virtue of the presence of such a space station makes its existence as part of the IPP very desirable. Even in a worst-case consideration the station would relegate potential hazards to positions of considerably less concern to the crews of the lunar complex and to mission control on Earth.

It is strongly recommended that the space station be made a mandatory part of the lunar complex and that no exploration of the surface begin until such time that the station is activated and manned.

3.2 THE LUNAR COMPLEX WITH AND WITHOUT A PROPELLANT DEPOT ON THE LUNAR SURFACE OR IN LUNAR ORBIT

FUNCTIONS OF A PROPELLANT DEPOT

Whether located on the lunar surface or in lunar orbit, a propellant depot would be used to supply or resupply any spacecraft with propellant to be used for descent to and ascent from the lunar surface, for spacecraft performing orbital maneuvers in connection with experiments or rescue, and for the lunar space station in its performance of station-keeping or any essential orbital maneuvers.

A second use of a propellant depot would be to supply oxygen for the environmental control system for any spacecraft, surface vehicle, or lunar base. The depot could also supply oxygen and hydrogen for fuel cells for any spacecraft, surface vehicle or base using the cells for electrical power.

In the event that a prime transport vehicle (PTV) used an excessive amount of propellant in its trip to lunar orbit, the depot could be used to resupply propellant to that transport vehicle.

The orbital depot may alternately be attached to the space station, may station-keep at some fixed distance from the station or may be maneuverable so that it can be relocated for the performance of its functions. On the lunar surface, the depot is most likely to be fixed with the option of moving separate tanks via a large rover type of surface vehicle.

POTENTIAL HAZARDS DUE TO THE PRESENCE OF A PROPELLANT DEPOT

For a depot in lunar orbit the following potential hazards exist, although from a practical viewpoint the likelihood of actual occurrence of any of them does not appear to be very great. Nevertheless, appropriate precautions and preventive measures should be taken to obviate their occurrence.

1. Collision between depot and another spacecraft.
2. Explosion of a propellant tank due to a meteoroid strike.

3. A leak in a propellant tank places the depot on a collision course with the lunar space station.
4. An EVA astronaut on umbilical gets entangled in depot structure.
5. A propellant tank is mishandled when being transferred to depot, 'escapes' to form a hazard in depot - OLS orbit.

All of these hazards are considered in Hazard Study 13, together with the corrective measures suggested to anticipate and dispose of such hazards.

The only hazard in the list above that appears in consideration of a surface depot is number 2. The closely related hazard of the depot being struck by lunar ejecta due to the engine plume of a nearby tug ascending to or descending from lunar orbit is disposed of by proper relative locations of depot and tug landing pads. The hazard of propellant tank handling during arrival at the surface depot is discussed as hazard number 2 in Hazard Study 20. (Module handling leading to tip-over and injury or damage during arrival and location of lunar base modules).

Because of its fixed position, the depot can be protected against micro-meteoroids by constructing overhead barriers, by placement close to a crater rim, by construction of walls made of lunar surface material or of materials brought from Earth. Excavating a recess in the surface to contain some or all of the depot would give added protection to the depot.

SAFETY ADVANTAGES OF A PROPELLANT DEPOT

A depot in lunar orbit would ensure to a large degree that insofar as the propulsion capacity and delta velocity capability of the space tug is concerned no mission would be left undone. The capability to perform rescue missions is of major importance in this respect. A depot would ensure the availability (and therefore remove the potential hazards due to depletion) of oxygen and hydrogen as each may be needed for fuel cells, environmental control, station-keeping functions for the space station and for any other presently unforeseen propellant requirements.

POTENTIAL HAZARDS DUE TO THE ABSENCE OF A PROPELLANT DEPOT

Not having the depot, in terms of these potential needs, presents a whole spectrum of potential hazards which include:

- (a) Isolation of crew members in orbit or on the surface because of insufficient propellant capacity for a tug.
- (b) Inability to complete or initiate a rescue because of propellant insufficiency.
- (c) Shortage of supplies to operate fuel cells.
- (d) In the event of a contaminated atmosphere in the space station or in the LSB the depot would be a source of fresh oxygen for replacement of the atmosphere. Nitrogen could also be stored at a depot for atmospheric replenishment.

An auxiliary depot on the surface would ensure the availability of oxygen and hydrogen as indicated in (a) to (d) above and would particularly ensure propellant sufficiency for any tug that intended to ascend to lunar orbit from the LSB area.

If no depot exists in orbit, then a surface depot must exist to keep landed tugs filled in order to pursue certain rescue missions such as a PTV failure to inject into lunar orbit. Otherwise, the PTV propulsion failure hazard might result in the loss of the crew aboard that vehicle.

Should no depot exist either in orbit or on the surface and the requirement for rescue of the crew of a failed PTV still exist - as it may - then a surface-based tug would have to be huge in order to accomplish this mission. For example, choosing an average response time (see Ref. a., pg, 223, 8 hr. response time) the delta velocity requirement for this mission is 24,600 fps: this includes 8000 fps to escape from the lunar surface, 4600 fps to chase the PTV, 5600 fps to return to lunar orbit, and 6300 fps to return to the lunar surface. In the context of the IPP the economic viability to counter this endangered PTV crew hazard, using so large a tug, is poor.

The present single stage configuration stationed in lunar orbit could perform this task at much lower cost and with far less exposure to hazards; viz., the lunar ascent and descent.

In sum, the potential hazards that are obviated and the advantages gained, as discussed herein, lead to a strong recommendation that a propellant depot be stationed and maintained in lunar orbit as a fundamental part of the lunar complex.

Because personnel and traffic levels are expected to increase downstream in time, it is also recommended that a depot be located on the surface eventually.

3.3 TUG DESIGN EFFECTS SINGLE STAGE VS TWO STAGE VS ONE AND ONE-HALF STAGE CONFIGURATIONS

TUG FUNCTIONS

The lunar tug propulsion functions consist of:

- (a) Delivery of personnel and/or cargo to the lunar surface and the return of personnel/cargo to lunar orbit. This function can occur between the lunar space station and the surface or between a prime transport vehicle (PTV) or another orbiting tug and the surface.
- (b) Transfer of cargo and personnel in lunar orbit to and from the PTV's and to and from the lunar space station.
- (c) Perform rescue missions:
 - 1. lunar surface to lunar surface
 - 2. lunar orbit to lunar orbit or beyond (e.g., past the Moon or to Earth)
 - 3. lunar orbit to lunar surface
 - 4. lunar surface to lunar orbit

TUG CONFIGURATIONS

There are presently three configurations being studied for the space tug to be used in the lunar complex; these include a single stage refuelable tug, a two-stage tug analogous to the Apollo Lunar Module, and a $1\frac{1}{2}$ stage tug in which propellant tanks are jettisoned when they are expended.

THE SINGLE STAGE TUG

The single stage tug has the evident potential hazard of propulsion failure during ascent or descent with no alternative mode or additional stage with which to recover. A potential method of obviating this shortcoming is to design the propulsion system with 4 engines located 90 degrees apart and operating as redundant diametrically opposed throttleable pairs. The engines would be operated simultaneously at $\frac{1}{2}$ of their rated thrust value

during tug ascent or descent missions. In the event of an engine malfunction its diametric twin would be turned off and the other pairs of engines would come up to full thrust to complete the mission. If the engines are built as separately replaceable units, then replacement of malfunctioned engines could be performed in orbit at the space station or on the surface at the LSB after the time it is activated.

Some redundancy could be placed in the propellant tanks by dividing the tanks into 4 or 6 units (2 or 3 tanks of LO_2 and 2 or 3 tanks of LH_2) and designing-in appropriate crossfeeds in the event of a tank or tank pressurization failure.

The engine/tank redundancy, plus similar treatment for tug controls, largely define the preventive measures against the hazards of propulsion/control failures during ascent or descent procedures.

Failures in 2 engines not diametrically opposed lead to an irrecoverable situation in which the crew would be lost.

It should be observed that the suggested alternate propulsion design concepts for the tug would reduce the hazards of propulsion failure substantially during descent and that this is aided by the assumption that normally at initiation of descent the tug's propellant tanks are full. The situation is not the same for ascent conditions. A propulsion failure during ascent is critical because a large percentage of the propellant has been expended during descent and the remainder may be close to marginal for completion of ascent so that if only part of it is available (i.e., a tank failure is involved) the tank and other redundancies may be insufficient to avoid an ascent failure. Thus, ascent missions even with the alternate concept advantages will still be hazardous.

Failures in other subsystems for the single stage tug cannot be discussed presently because knowledge on these subsystems is not now available. It is expected, however, that such critical subsystems as electrical power will be redundant to the extent of supplying back-up electrical power during ascent or descent.

THE $1\frac{1}{2}$ STAGE TUG

All of the considerations given to the single stage configuration apply to the $1\frac{1}{2}$ stage. However, jettisoning tanks clearly implies the need for tank replacement at some later time. The handling of these tanks presents a hazard not found in the single stage tug to the crew whether replacement occurs in lunar orbit or on the lunar surface. Because of the need for tank jettisoning the $1\frac{1}{2}$ stage tug is, to some degree, less safe during operation than the single stage tug, since, if the tank jettisoning fails to take place the tug propulsion performance will be degraded.

The hazards to be met in ascent with the $1\frac{1}{2}$ stage configuration are little different from those in the single stage tug.

THE TWO STAGE TUG CONFIGURATION

The hazards of stage failure in any lunar descent procedure are circumvented by the use of a two stage Apollo-LM type lunar lander. However, the ascent hazard remains since in this configuration the lower stage serves only as a launching platform for the ascent stage and as a consequence can play no part in any ascent procedure. All of the ascent hazards to be found in one and in the $1\frac{1}{2}$ stage configurations are still present in the upper stage of the two stage configuration. The use of two pairs of engines/controls as described for the single stage configuration would essentially overcome the ascent hazard in the two stage lander. This still gives engine redundancy and does not require a separation sequence. In the event of an aborted descent the potential hazard of being isolated in orbit is relieved by the ability to perform rescue by other manned vehicles in lunar orbit. Such potential rescue vehicles could be docked at the space station or may constitute a manned tug in lunar orbit by itself. An ascent procedure may also be aborted if the velocity gain at the time of decision-to-abort is not more

than approximately 2000 ft/sec and propulsion and attitude control are functioning. However, some provision for landing support hardware would have to be included on the ascent stage for such a procedure. It is readily realized that this kind of ascent abort would provide hazard circumvention in only part of the spectrum of hazards during ascent; still, because it is a reasonable technique, it should not be neglected. The technique is applicable to all 3 configurations discussed in this section. The 2 stage and $1\frac{1}{2}$ stage tugs introduce additional hazards by virtue of the need to replace the descent stage or the jettisonable tanks. There appears to be no sharp differences among the three configurations insofar as the presence or lack of hazards are concerned in the light of presently available information.

Because of the lack of detailed information on the 3 tug configurations no recommendation can be made at this time depicting the least hazardous of these 3 concepts.

It is strongly suggested, however, that when detailed designs of all three configurations are available a study in depth be conducted to ascertain the hazards present and the relative safety of the 3 tug configurations.

APPENDIX A
LUNAR MISSION HAZARDS CHARACTERIZATION

This Appendix assembles and presents information relative to the characterization of the hazards which might be encountered in projected lunar exploration missions. It also presents the pertinent definitions, cause and effect relationships and hazards groupings employed in the Lunar Mission Safety and Rescue Study - Hazards Analysis Task.

1. Pertinent Definitions (Ref. 1)

Safety -- Freedom from chance of injury or loss to personnel, equipment or property.

Hazard -- The presence of a potential risk situation caused by an unsafe act or condition, environment or natural phenomenon, personnel error, design characteristics, time critical normal or emergency operations, procedure deficiencies, or subsystem malfunction which will cause system or personnel loss.

Risk -- The chance (qualitative) of injury to personnel or loss of equipment, or property.

Personnel Loss -- Loss of function or injury requiring medical attention.

Hazard Levels -- Hazardous levels are identified as follows:

Safety Catastrophic -- Condition(s) such that environment, personnel error, design characteristics, procedural deficiencies, or subsystem malfunction will cause system or personnel loss.

Safety Critical -- Condition(s) such that environment, personnel error, design characteristics, procedural deficiencies, or subsystem malfunction must be counteracted by urgent crew action (no time available

for ground/flight crew analysis) to prevent system or personnel loss.

Safety Marginal -- Condition(s) such that environment, personnel error, design characteristics, procedural deficiencies, or subsystem malfunction can be counteracted or controlled with time available for ground/flight crew analysis to prevent system and/or personnel loss.

Safety Negligible -- Condition(s) such that personnel error, design characteristics, procedural deficiencies, or subsystem failure will not result in system or personnel loss.

2. Hazards Groups

The selection of specific hazards groups considered in the study is based upon the recognition of a direct relationship between the cause of a hazard, its potential effects upon exposed crew personnel and the implied threat to personnel safety which the hazard may inherently contain (Ref. 2). It is felt that any hazards group classification scheme adopted must account for this relationship in order to avoid the purely mechanistic or system-oriented approach which neglects crew personnel as functioning entities. The implications of the cause, effect and threat relationship are apparent from an examination of the following:

<u>PRIME CAUSES</u>	<u>POTENTIAL EFFECTS</u>
EQUIPMENT FAILURES	FATALITIES
ENVIRONMENTAL HAZARDS	INCAPACITATION
FUNCTIONAL INCAPACITATION	DEBILITATION
PERSONNEL ERRORS	DISORIENTATION
PROCEDURAL ERRORS	TRAUMA

BASIC THREATS

DEPRIVATION OF METABOLIC NEEDS

ORGANIC DAMAGE AND POISONING

EXCESSIVE PHYSIOLOGICAL STRESS

EXCESSIVE PSYCHOLOGICAL STRESS

Note that the presence of a basic threat in any of the prime causes of a hazardous situation or condition will generate a potential risk to crew personnel.

A review of the work performed by previous investigators in the determination of logical hazards classification groupings was accomplished. The various groupings were compared for similarity, applicability and completeness, and then additionally checked against the cause, effect, threat relationship to determine specific applicability to crew personnel safety. The results of this effort were incorporated into a listing of hazards groups which appear to adequately characterize the range of hazards one might expect to be associated with a lunar exploration program. For the purpose of the current study, it was determined that a revised listing of twelve general classification groups were sufficient to describe the hazards most likely to be encountered in the hazards analysis.

The hazards groups are as follows:

- | | |
|------------------------|-------------------------------------|
| 1. EXPLOSION/IMPLOSION | 7. PERSONNEL ISOLATION |
| 2. FIRE | 8. MOTION/ACCELERATIONS |
| 3. PRESSURE EXCURSION | 9. HUMAN ERROR |
| 4. COLLISION | 10. HOSTILE ENVIRONMENT |
| 5. CONTAMINATION | 11. RADIOLOGICAL HAZARDS |
| 6. INJURY/ILLNESS | 12. SYSTEM OR SUBSYSTEM MALFUNCTION |

A brief discussion of each hazard group is given in the interest of clarity of definition:

1. Explosion/Implosion: - The hazards attendant to, and/or occasioned by sudden and violent disruption of vehicle, shelter, or contiguous equipment component integrity.

Includes: Explosion or Implosion due to: State transformation of liquids, gases, chemicals, or ordnance sources, or induced transformations due to heat and/or pressure sources.

2. Fire: - The hazards attendant to, and/or occasioned by slow or rapid combustion of vehicular, habitat, or suit materials capable of sustained burning once ignited.

Includes: Liquids, gases, organic based materials, pyrophoric metals.

3. Pressure Excursions: - The hazards occasioned by any non-violent decompression/over-pressure event occurring in vehicle, habitat or suit, outside of established pressure limits.

Includes: Unplanned venting, pressure loss, unplanned inflation, unplanned deflation, etc.

4. Collision: - The hazards occasioned by impact with natural or man-made objects whether originating from internal (vehicle, shelter) or external sources.

Includes: Meteoroid strikes, debris, unsecured equipments, other vehicles, lunar surface objects, etc.

5. Contamination: - The hazards occasioned by the presence of an elemental or structured substance, or biological organism, whether toxic or non-toxic, which exceeds specified permissible concentration limits for the surface, fluid or media under consideration.

- Includes: (a) Substances or organisms which are inimical to human life or intolerable for human well-being.
- (b) Substances which can impair or destroy mechanical/electrical/electronic equipments.

6. Injury/Illness: - The hazards attendant to, and/or occasioned by a condition in which the health and well-being of the crew or a crew member is impaired or destroyed, due to organic damage or degradation or to biological invasion.

Includes: Fractures, punctures, lacerations, concussions, metabolic deprivation, diseases, infection, death. (Refs. 2 and 3).

7. Personnel Isolation: - The hazard occasioned by a condition or situation wherein a barrier exists between a crewman and his haven of safety.

Includes: Stranding, entrapment, communication loss, loss of reference position, visibility difficulties, etc.

8. Motion/Accelerations: - The hazards occasioned by the movement of personnel, or of space or surface vehicles, whether planned or unplanned.

Includes: Ascent, descent, braking, injection, deorbiting, linear motion, roll, pitch, yaw, turning, reversing, tumbling, etc.

9. Human Errors: - The hazards occasioned by accidental or unintentional departure from established plans or procedures. Impaired awareness of, or misjudgment regarding, a situation and a course of action required.

Includes: Inadvertent or accidental activation of systems (button pushing, switching, etc.); failure to check out, enable, or arm systems;

fatigue-induced impaired awareness regarding sequential processes or procedural requirements and back-up modes; incomplete assessment of situation or condition at hand, etc.

10. Hostile Environment: - The hazards attendant to, and/or occasioned by exposure to external environmental conditions which may be inherently destructive to human life.

Includes: External temperature extremes, space vacuum conditions, and extraterrestrial body environments (i.e., planetary atmospheric gases, dust, life-forms, spores, reactive materials and liquids, lighting phenomena, gravity conditions, etc.)

11. Radiological Hazards: - The hazards attendant to, and/or occasioned by, natural or man-made electro-magnetic and nuclear radiation sources.

A. Natural Sources: External electromagnetic radiation, cosmic radiation, solar flares, and by-products of stellar nuclear reactions.

Includes: Galactic cosmic rays, Van Allen belts, high and low energy protons, high and low energy electrons, Alpha particles, solar wind and flares (Refs. 4 & 5).

B. Man-Made Sources: Energy radiating equipments, of all types emitting penetrating rays, beams and particles.

Includes: Radio transmitter microwave, X-ray, radar, laser-beams, radio-isotopic power generators, nuclear power plants, and nuclear propulsion systems.

12. System or Subsystem Malfunction: - The hazards attendant to, and/or occasioned by, a system or subsystem malfunction, whether due to a failure to perform, or to performance degradation.

Includes: Any system, subsystem, or equipment item (hardware/software), the functional capability of which is critical to the execution of a local or remote operation or activity.

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3. "Summary of Medical Experience in Apollo 7 through 11 Manned Space Flights," C. A. Berry, NASA/MSC, Aerospace Medicine, May 1970.
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APPENDIX B
LUNAR MISSION MODEL

An advanced lunar exploration program proposed for the 1980 to 1990 time period must be fluid and open to change during the next several years. Equipment designs, operational interfaces, operational safety, exploration objectives, national priorities, and budgets will be among the factors continually traded off in working toward a firm, approved program. In the meantime, safety requirements must be developed in order that the equipment elements may be designed and exploration programs planned to provide the lunar explorers of the future with a safe operation.

The development of safety guidelines or requirements must proceed from knowledge of the hardware elements to be used and the operations and schedules to be supported. It is evident that this development process must be iterative. For the Lunar Mission Safety and Rescue Study it was necessary that a model program, with alternates, be chosen to expose the potential hazards to man. The baseline model provided by NASA was the Integrated Program Plan (IPP) Reference Schedule - High Budget Baseline dated 5-18-70 (Ref. 1), with the addition of alternate nuclear or chemical shuttles between Earth orbit and lunar orbit. The IPP Reference Schedule - Low Budget Alternative dated 5-27-70 (Ref. 2) was provided as a representative alternate program.

With the Integrated Program Plan (IPP) high budget model as a baseline, representative lunar mission operations were defined for use in the study. Equipment and operations data from current and past studies and actual Apollo missions were freely consulted in order to make the model as realistic as possible. Representative hardware elements and use descriptions were obtained from the NASA-MSD Project Description Documents (PDD's) for Space Tug, Nuclear Stage, Chemical Stage, Lunar Orbit Station, Fuel Depot, Lunar Surface Base, and Surface Transportation, References 3 through 9, respectively. The

mission model was summarized by NASA in Ref. 10.

As an analysis aid, Lockheed developed operations time-lines for the mission model. The basic traffic model is presented in Ref. 1. The lunar mission functional flow diagrams are presented in Appendix D of this report, MSC-03977.

The major items of spacecraft, lunar surface vehicles, surface installations, and other equipments that were considered to be a part of the lunar complex and were derived from the constituents of the high level IPP and associated PDD's include but are not limited to:

1. A space tug consisting of propulsion module, 6-man crew module, an intelligence module, a cargo module, and landing gear.
2. A Prime Transport Vehicle (PTV) which may have a chemical or nuclear propulsion system. The PTV transports men and cargo between Earth orbit and lunar orbit.
3. A 12-man space station in lunar orbit, together with auxiliary modules for purposes of conducting experiments and for supporting other space station activities.
4. A propellant depot in lunar orbit which may be attached to the space station or free flying but under the jurisdiction of the space station. At a date downstream in the lunar program, a supplementary depot may be established on the lunar surface.
5. Lunar surface cabin and non-cabin type roving vehicles.
6. Lunar flying vehicles which may be equipped to carry a pilot and a passenger.
7. A 6-man to 9-man Lunar Surface Base which is a multi-compartmented, multi-decked permanent installation on the lunar surface intended to support far-ranging surface exploration.

8. Lunar Shelters which may be brought to any site at which lunar activities will be conducted. They are considered temporary and movable structures.
9. Lunar scientific equipment which covers all and any equipment brought to the surface or to lunar orbit to directly aid in the spectrum of experiments to be conducted in the lunar complex.
10. Lunar Surface Support Equipment to be used in supporting all crew member activities including basic functions such as power for life support and extended functions such as the surface experiments. A nuclear based electrical power system is expected to be included when the LSB becomes an operating entity.
11. Unmanned lunar satellites supporting basic functions such as communications and other satellites used in the realm of scientific experiments.

It is emphasized that the models were used only as a necessary analysis aid and point of departure for a broad safety and rescue study. Every effort was made throughout the study to keep in mind that the objective was to develop safety guidelines and rescue concepts in a general sense in order to influence the design of new equipment and the planned operation of that equipment.

References:

1. NASA-MSC Integrated Program Plan Reference Schedule, High Budget Baseline - May 18, 1970.
2. NASA-MSC Integrated Program Plan Reference Schedule, Low Budget Alternative - May 28, 1970.
3. NASA-MSC Project Description Document - Space Tug - April 24, 1970.
4. NASA-MSC Project Description Document - Nuclear Stage - April 13, 1970.
5. NASA-MSC Project Description Document - Chemical Stage - May 5, 1970.
6. NASA-MSC Project Description Document - Lunar Orbit Station - April 1970.
7. NASA-MSC Project Description Document - Fuel Depot - April 14, 1970.
8. NASA-MSC Project Description Document - Surface Transportation - March 1970.
9. NASA-MSC Project Description Document - Lunar Surface Base - June 15, 1970.
10. Contract NAS 9-10969 Statement of Work, Appendix A, Description of Lunar Program Portion of Manned Spaceflight Integrated Plan - April 1, 1970, NASA-MSC.

APPENDIX C

HAZARD ANALYSIS METHODOLOGY

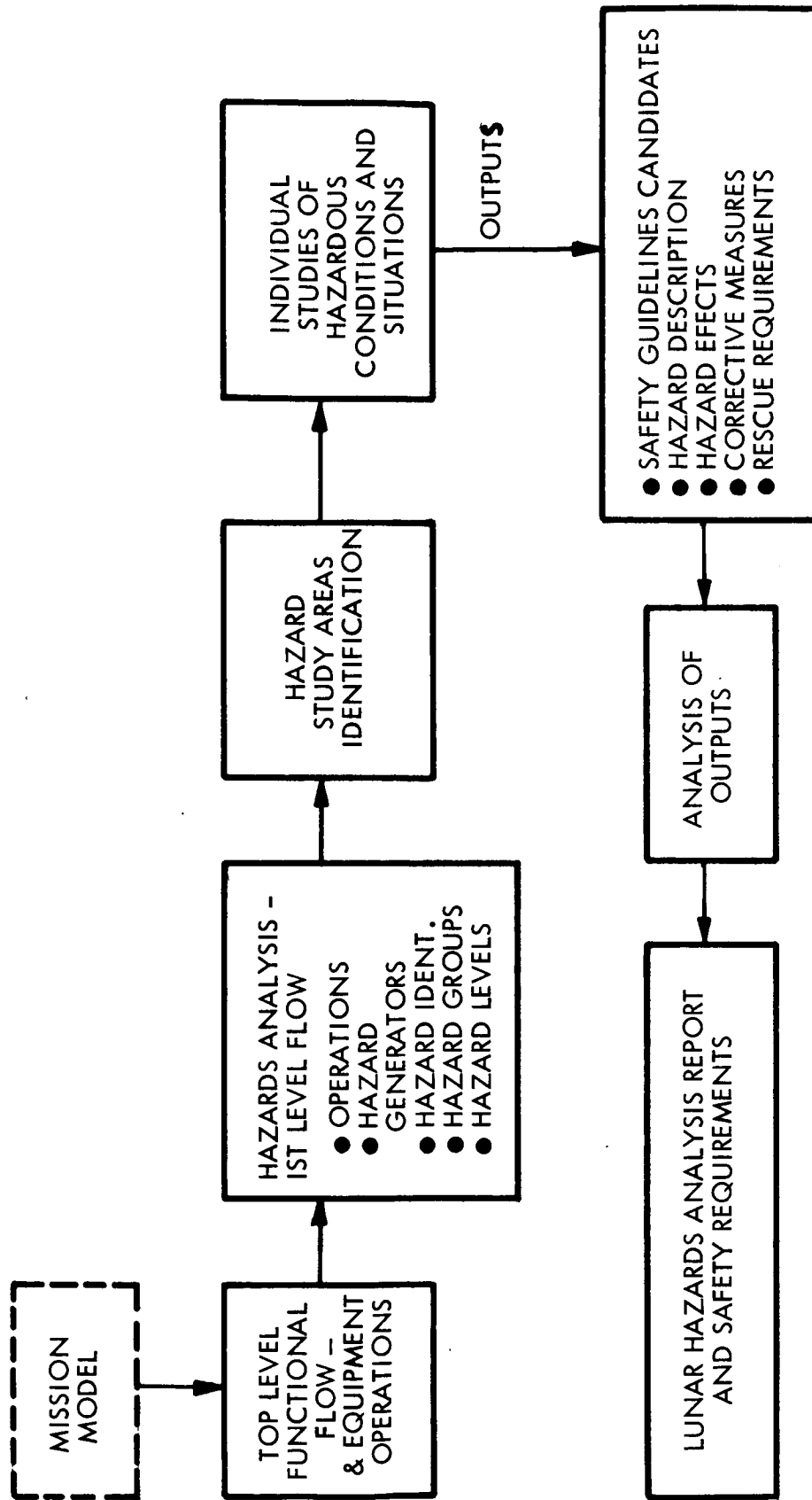
The hazards analysis proceeded from the task objectives and the mission model defined for the study as shown in Figure C-1.

The first step was to describe, in a top level flow diagram, the functions and operations of the lunar exploration elements making up the model. This top level functional flow diagram, presented in Appendix D, displays and links the major items of lunar exploration equipment and the major operations that take place with that equipment.

The top level flow diagram is then expanded in a series of first level flow charts to display mission events and identify potentially hazardous conditions and situations requiring study. The complete first level hazards assessment is presented in Appendix D and identifies hazard generators, hazards, potential hazard effects, applicable hazard groups, and the hazard level range.

Each event in the first level hazards assessment was examined, and a list of hazardous conditions and situations requiring further study was compiled. This list was then expanded to include special situations and conditions, such as lighting, communications, and lunar environment, not stated in the lunar mission program model of sequence of events. Each item on this list was subjected to an individual study to identify the hazards in greater detail, describe the hazards effects, propose alternate preventive and remedial measures, note requirements for escape and rescue, and present candidate safety guidelines and requirements. Section 2 of this report presents the complete results of the individual studies.

The first step in each Hazard Study was to state the assumptions important to the situation to be analyzed. Next, the major hazards were listed and



C-2

Fig. C-1 Hazard Analysis Methodology

described briefly. Each hazard was then analyzed to determine the effects on crew safety, and to perform trade studies of alternate corrective measures, both preventive and remedial. For each hazard, the possible need for escape and/or rescue was noted. The final step was preparation of a list of candidate safety guidelines and requirements. The completed Hazard Study was then passed on to the Escape/Rescue subtask team where the requirements were defined in greater detail and escape/rescue concepts and guidelines proposed.

With the individual studies complete, a study of the hazards identified and of the guidelines candidates was made to assess compatibility and feasibility and to firm up the recommendations presented in Section 2 of MSC-03976.

APPENDIX D

FIRST LEVEL HAZARDS ASSESSMENT

This appendix presents the first level hazards assessment described in Appendix C.

The top level functional flow, Fig. D-1, displays and links the major items of lunar exploration equipment and the major operations that take place with that equipment.

The top level flow diagram is expanded in a series of first level flow charts to display mission events and identify potentially hazardous conditions and situations that might occur in a typical advanced lunar program. For each event in the mission, the hazards generators, hazards, hazards groups, and hazard level range are identified.

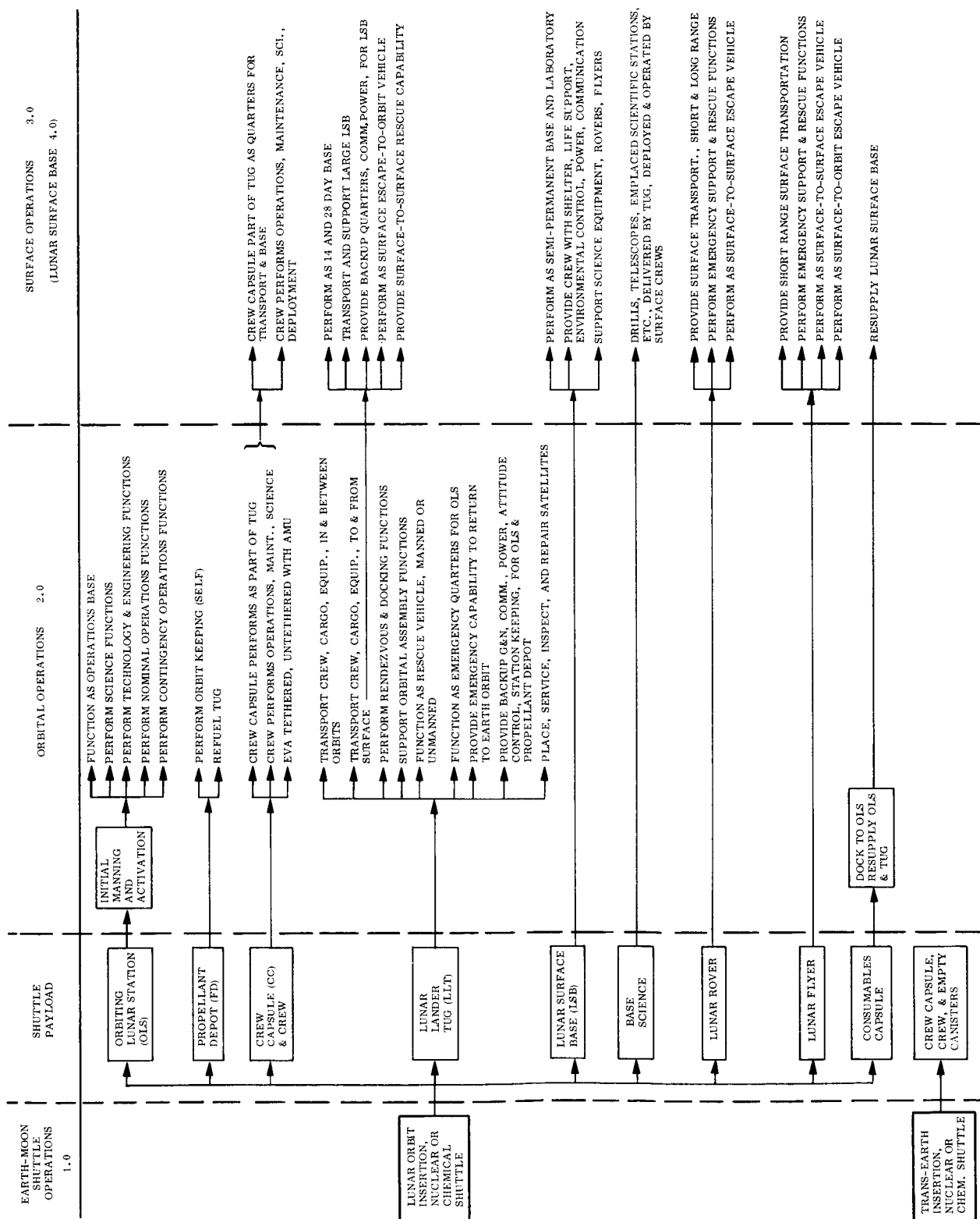


Fig. D-1 Top-Level Functional Flow - Lunar Mission Operations

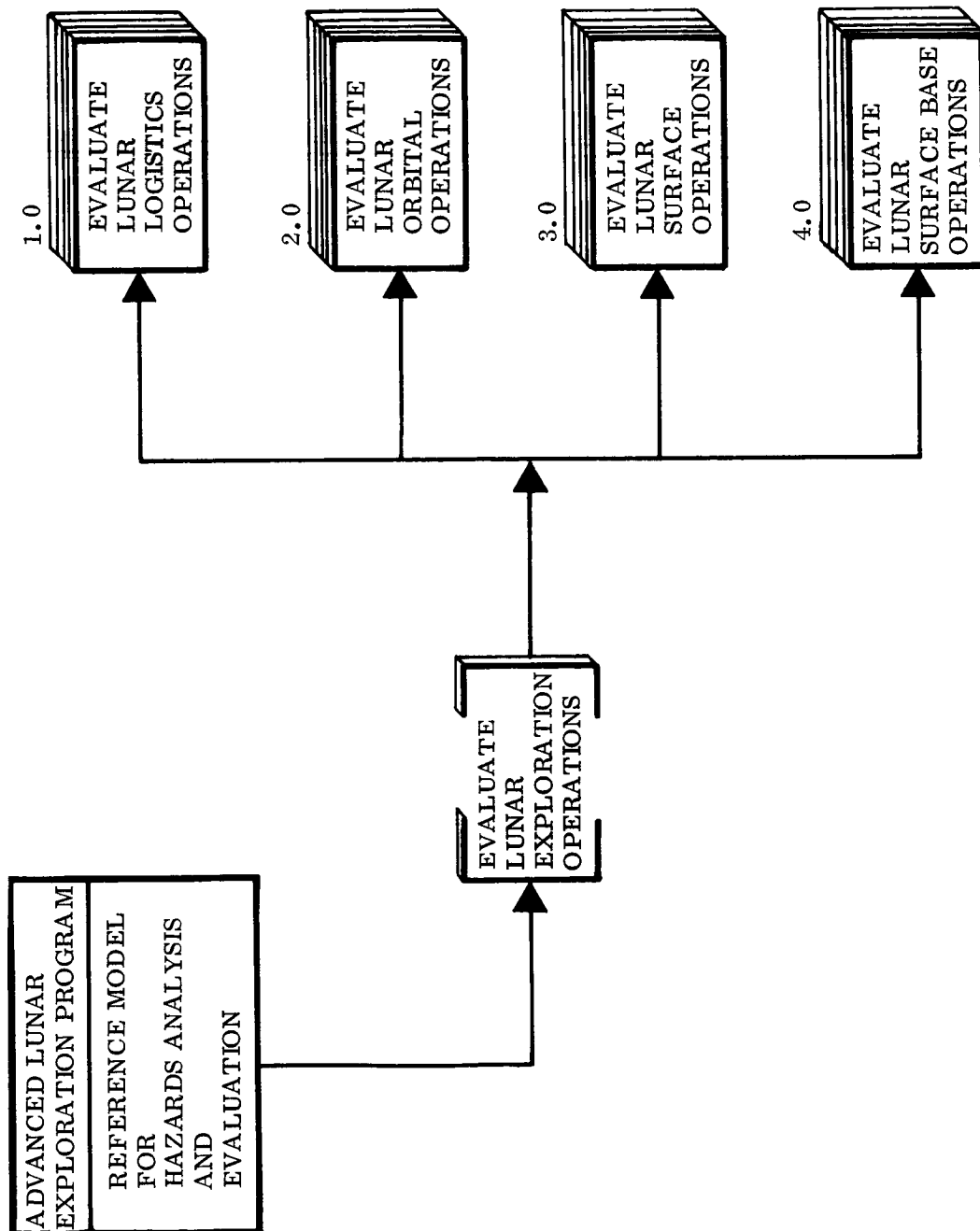


Fig. D-2 Model Top-Level Definition

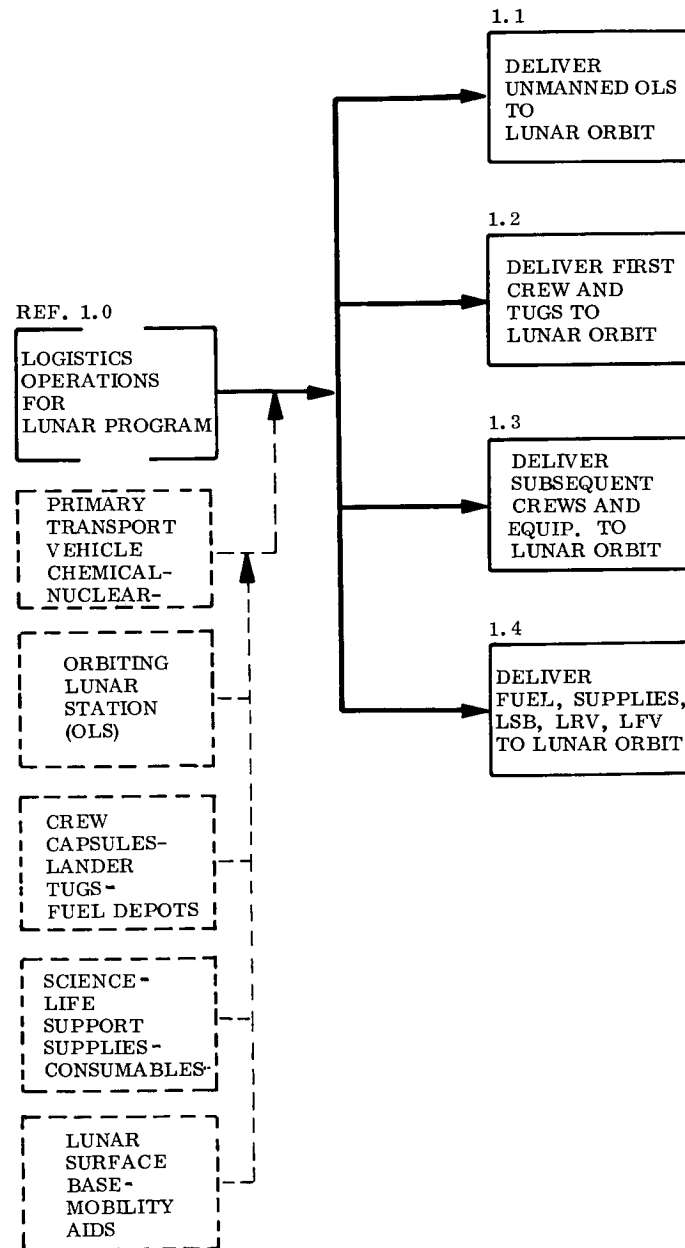


Fig. D-3 Logistics Operations First-Level Functions

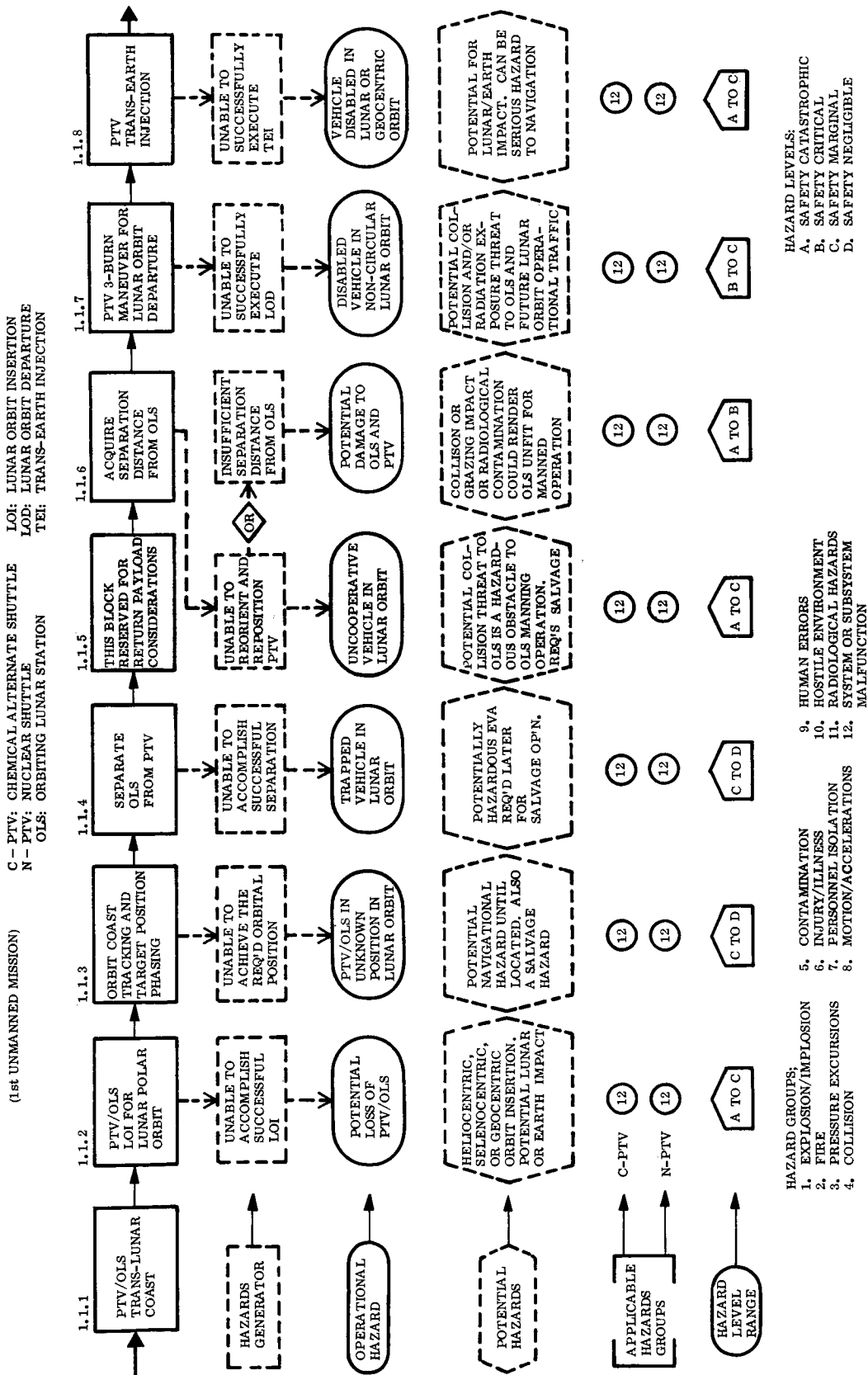


Fig. D-4 Logistic Operation - 1.1: Prime Transport Vehicle Delivery of Orbiting Lunar Station (PTV/OLS)

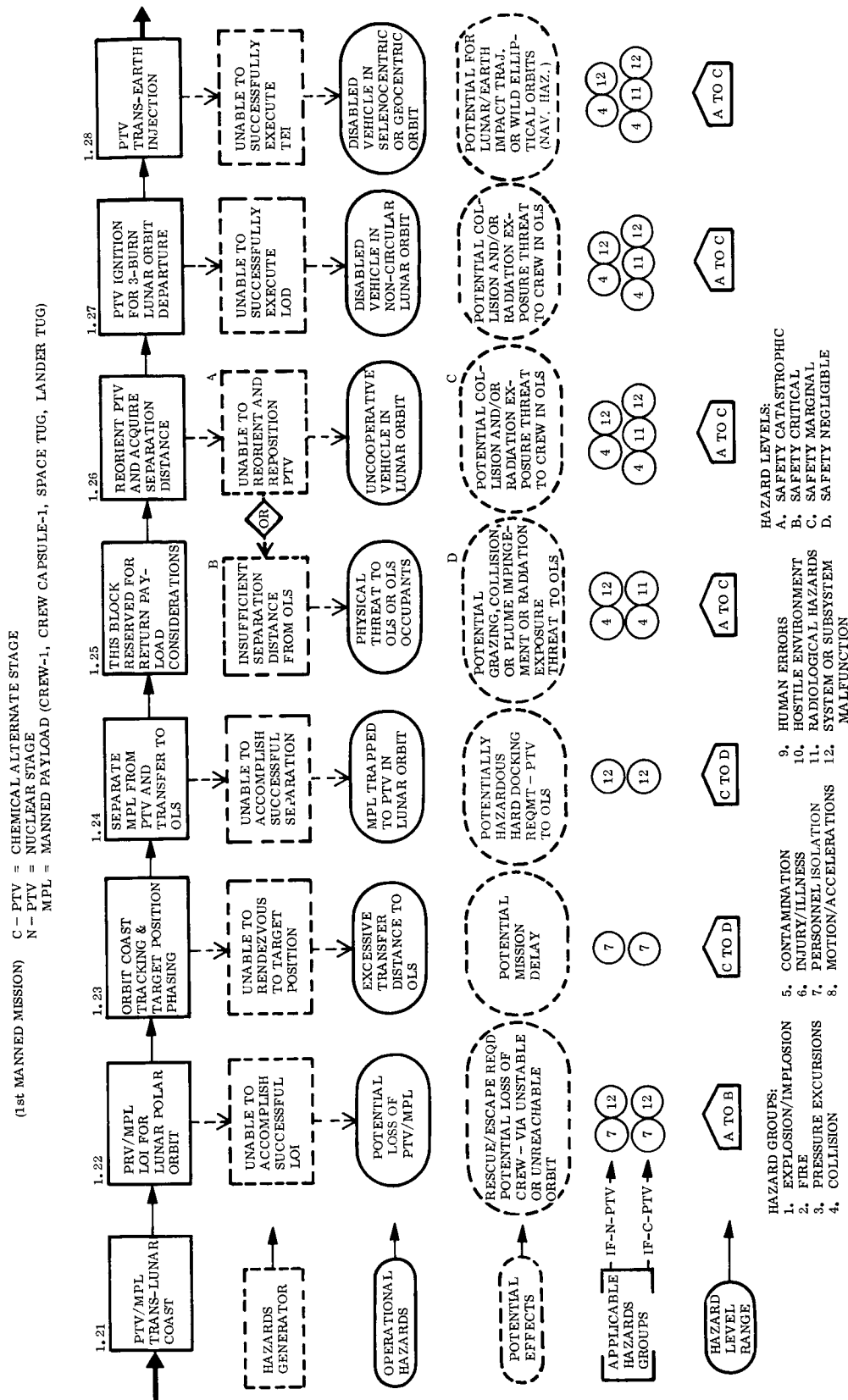


Fig. D-5 Logistic Operation - 1.2: Prime Transport Vehicle Delivery of Crew-1 and Tug Vehicles (PTV/MPL)

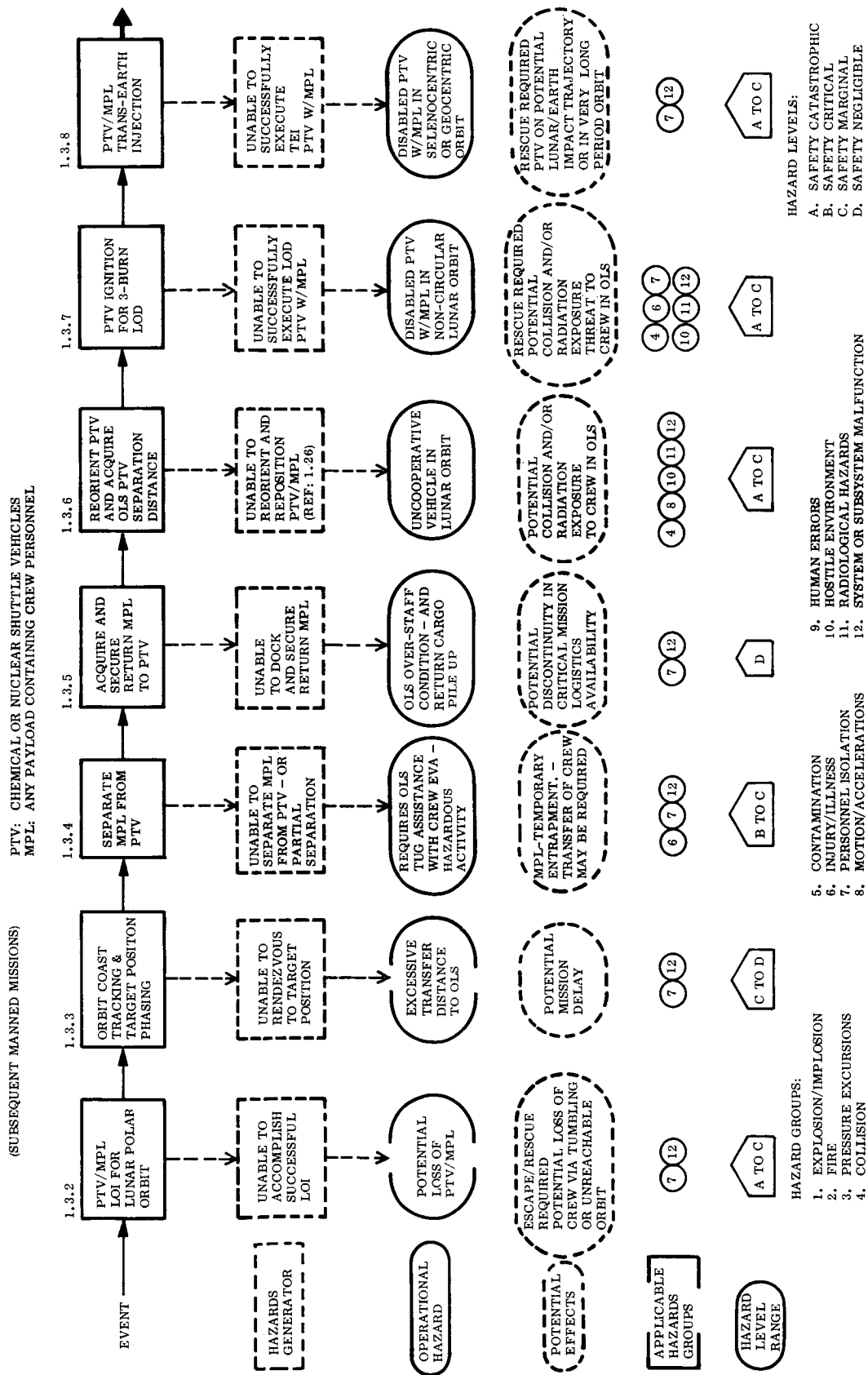


Fig. D-6 Logistic Operation - 1.3: Prime Transport Vehicle Delivery of Replacement Crew and Supplies (PTV/MPL)

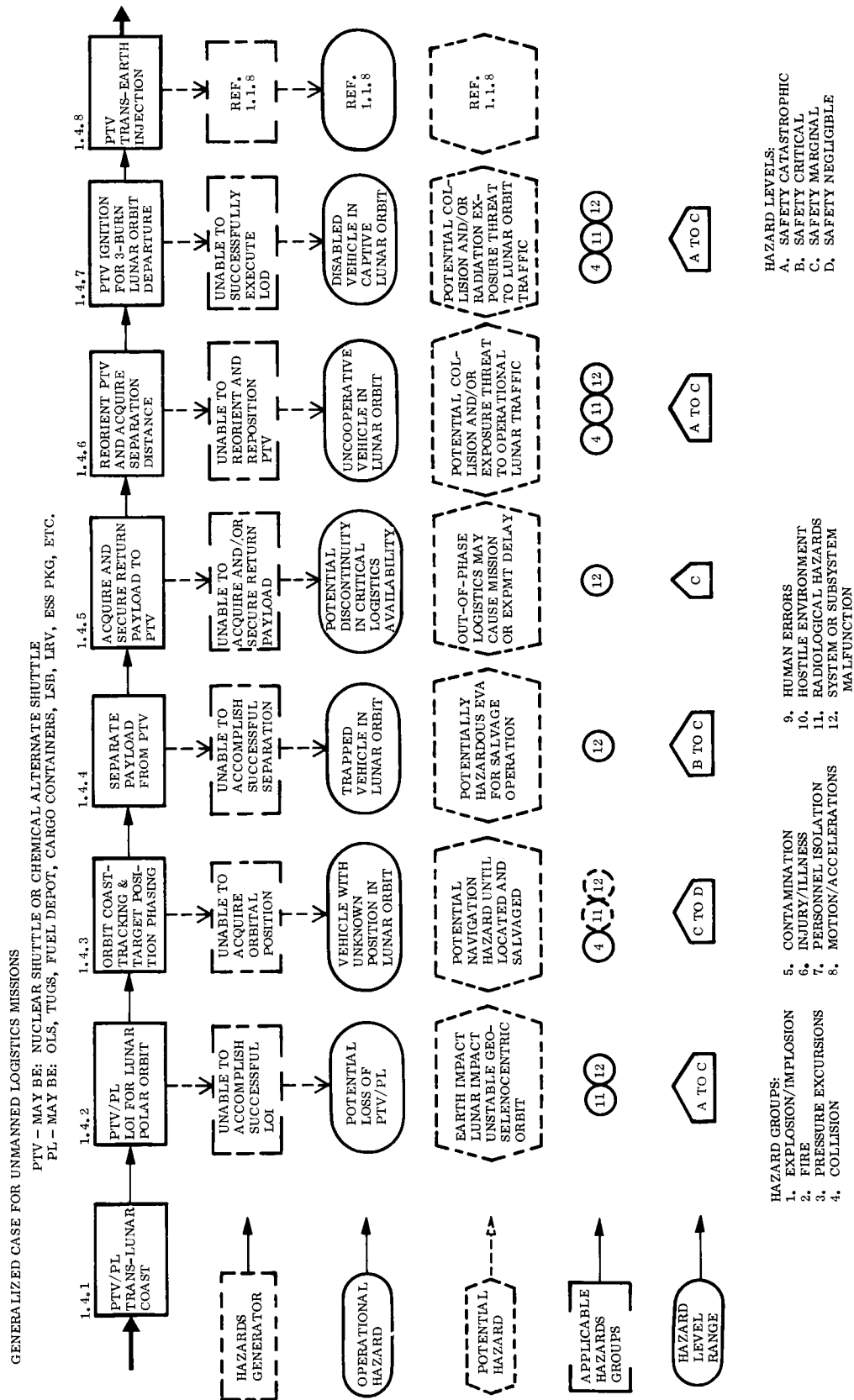


Fig. D-7 Logistic Operation - 1.4: Prime Transport Vehicle Delivery of Payload to Lunar Orbit (PTV/PL)

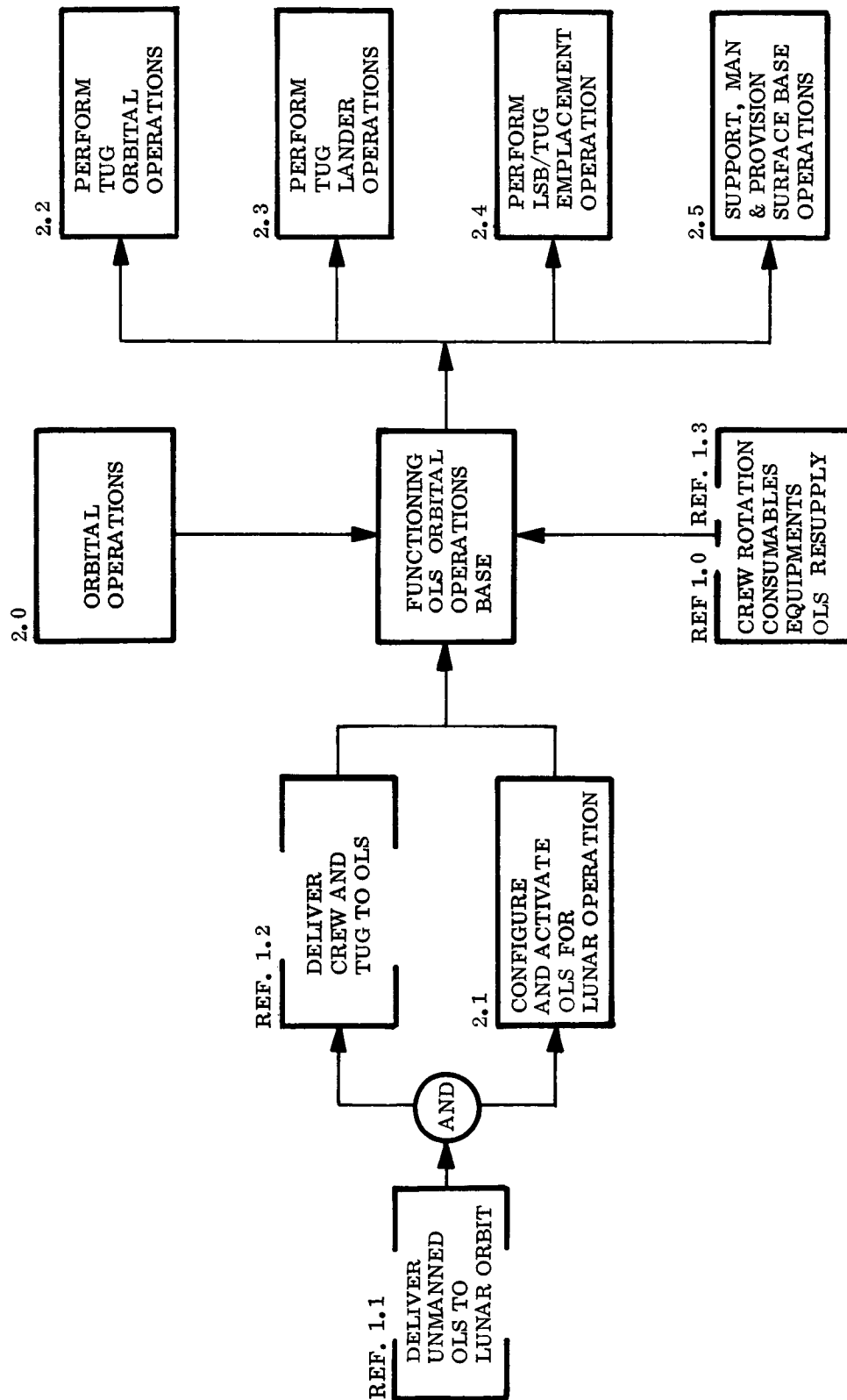


Fig. D-8 Orbital Operations First-Level Functions

OLS: ORBITING LUNAR STATION
MPL: CREW CAPSULE-1, CREW-1, LANDER TUG-1, CREW CAPSULE-2, LANDER TUG-2 (STACKED)

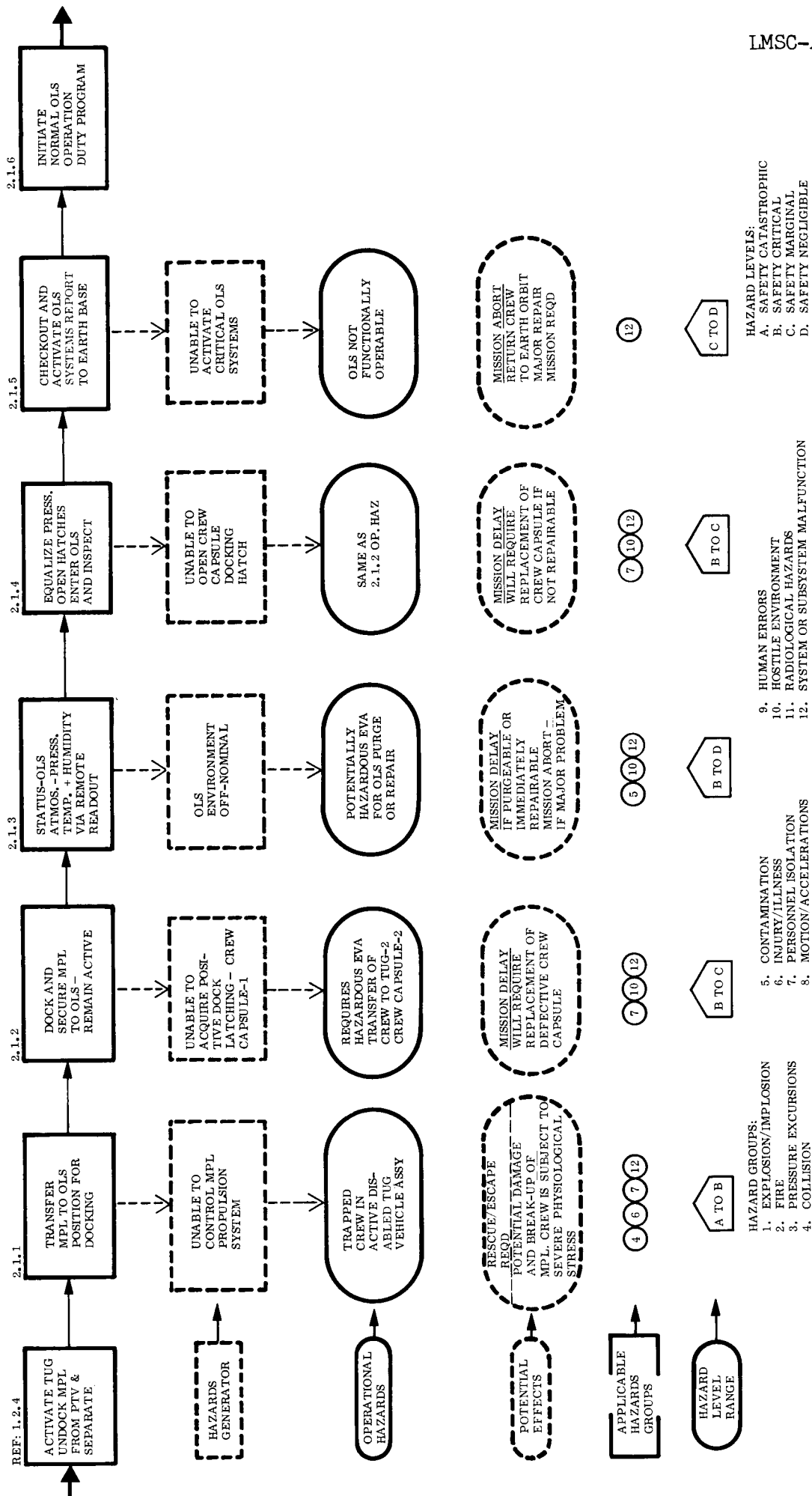


Fig. D-9 Orbital Operation - 2.1: OLS Activation - Initial
Orbital Activity

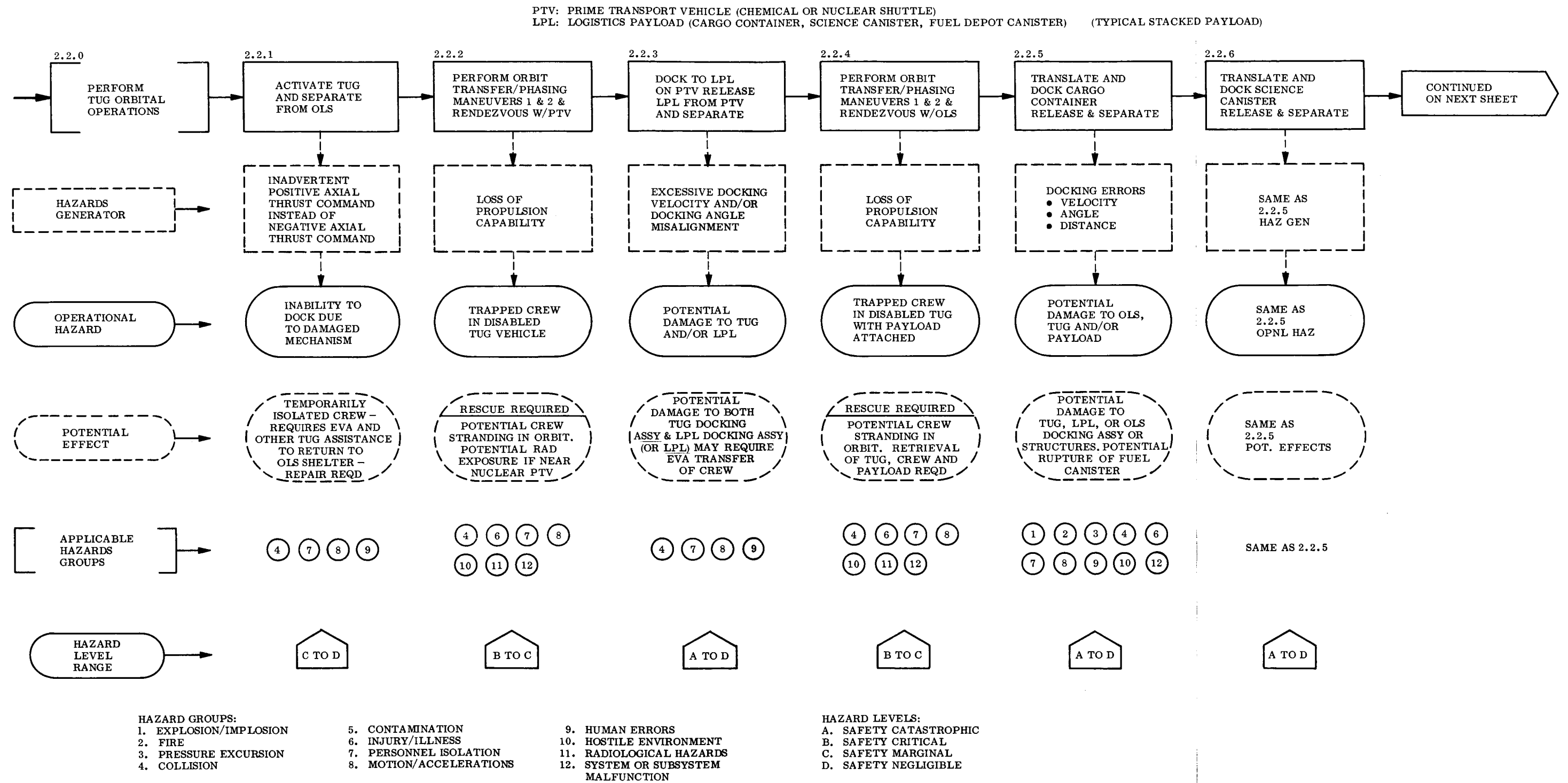


Fig. D-10 Orbital Operations 2.2: Tug Orbital Operations (Typical)

PTV: PRIME TRANSPORT VEHICLE (CHEMICAL OR NUCLEAR SHUTTLE)
LPL: LOGISTICS PAYLOAD (CARGO CONTAINER, SCIENCE CANISTER, FUEL DEPOT CANISTER)
FD: FUEL DEPOT

NOTE:
G&C: GUIDANCE & CONTROL
P.M.: PROPULSION MODULE

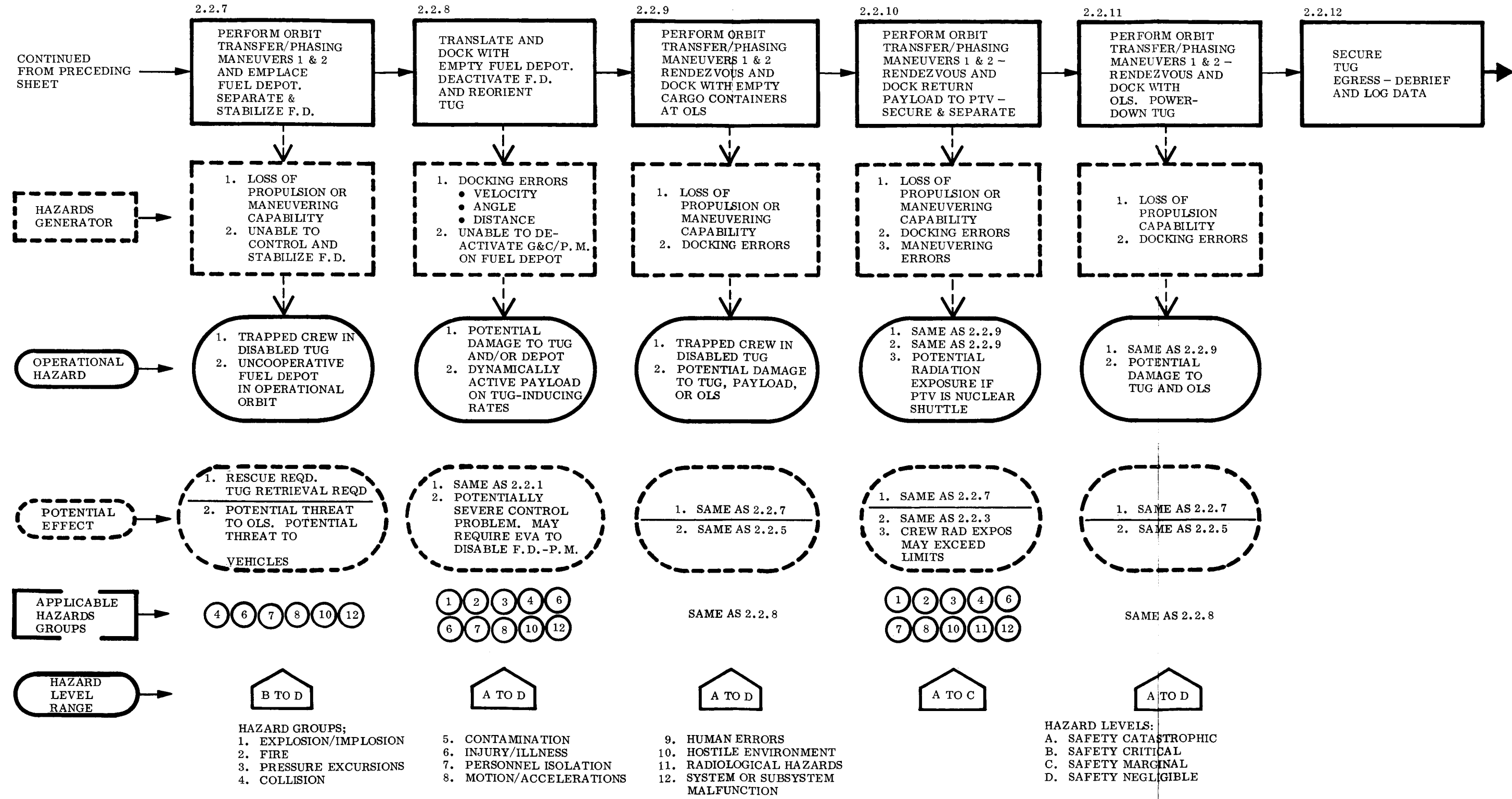


Fig. D-10 (Continued)

(NOTE: 2.3 HAS TWO SHEETS)

OLS : ORBITING LUNAR STATION
TUG : LANDER TUG WITH CREW CAPSULE AND CARGO CAPABILITY
PDPS: POWERED DESCENT PHASE SEQUENCE
ALPS: APPROACH AND LANDING PHASE SEQUENCE

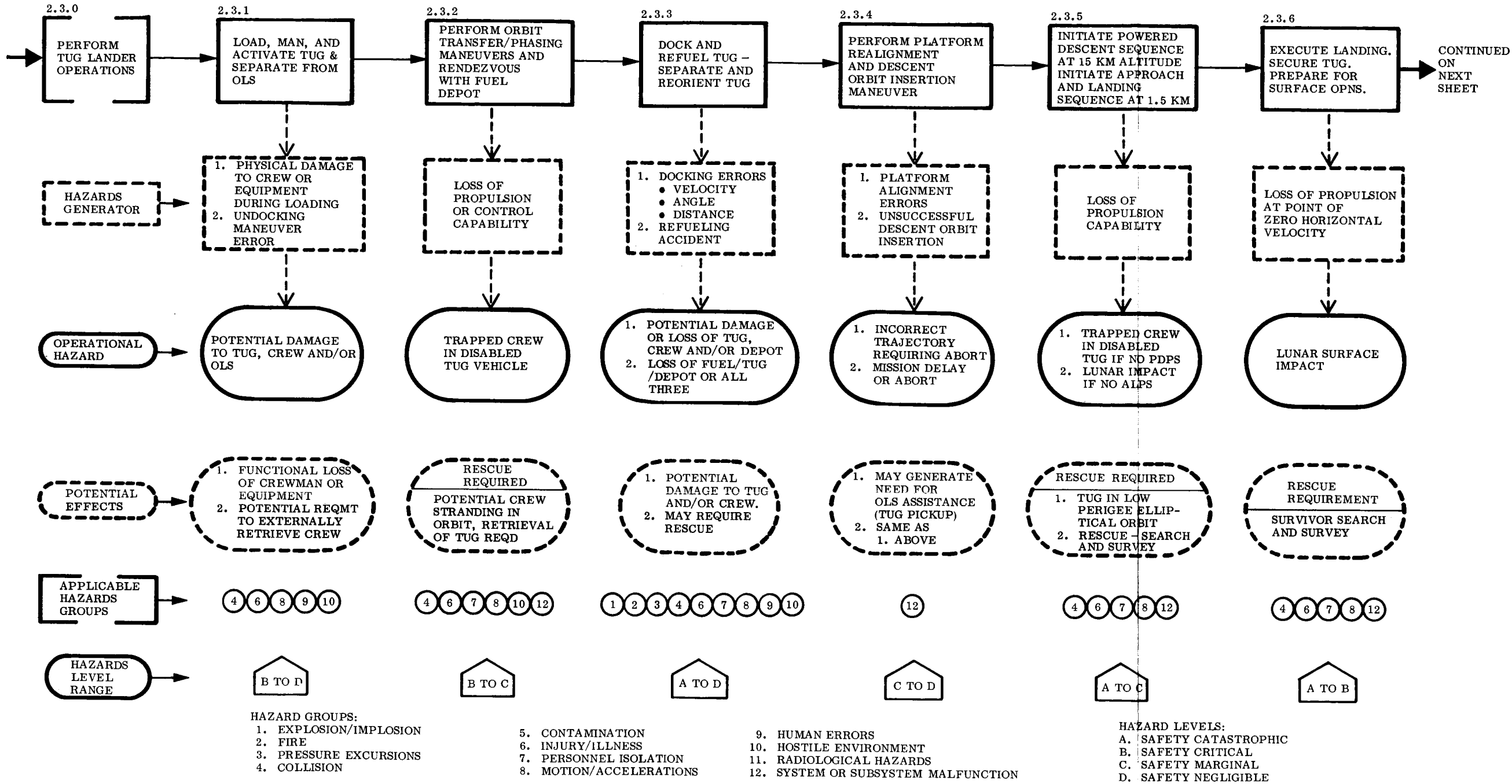


Fig. D-11 Orbital Operation - 2.3:
Tug Surface Descent
Operations (Typical)

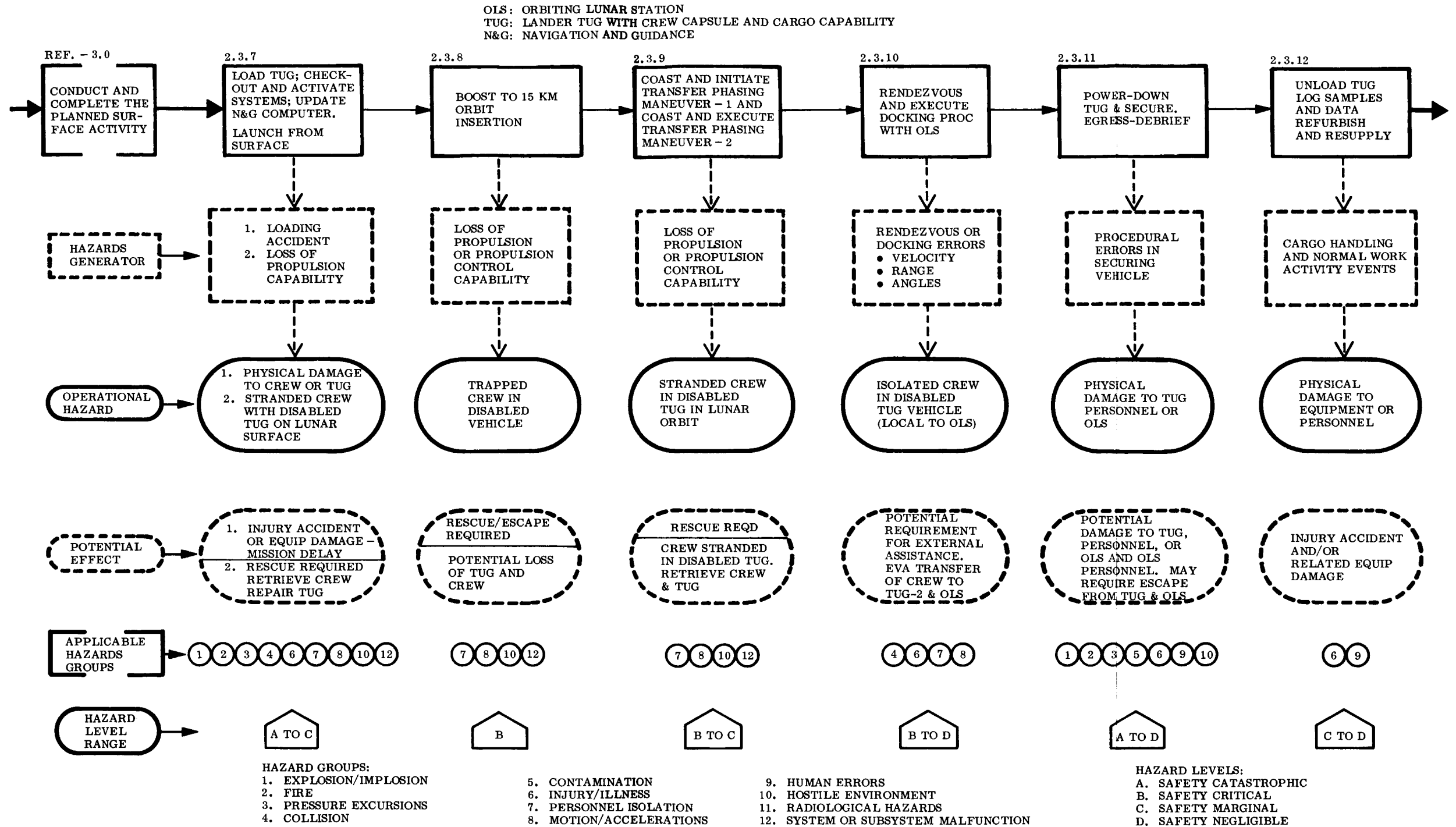


Fig. D-11 (Continued)

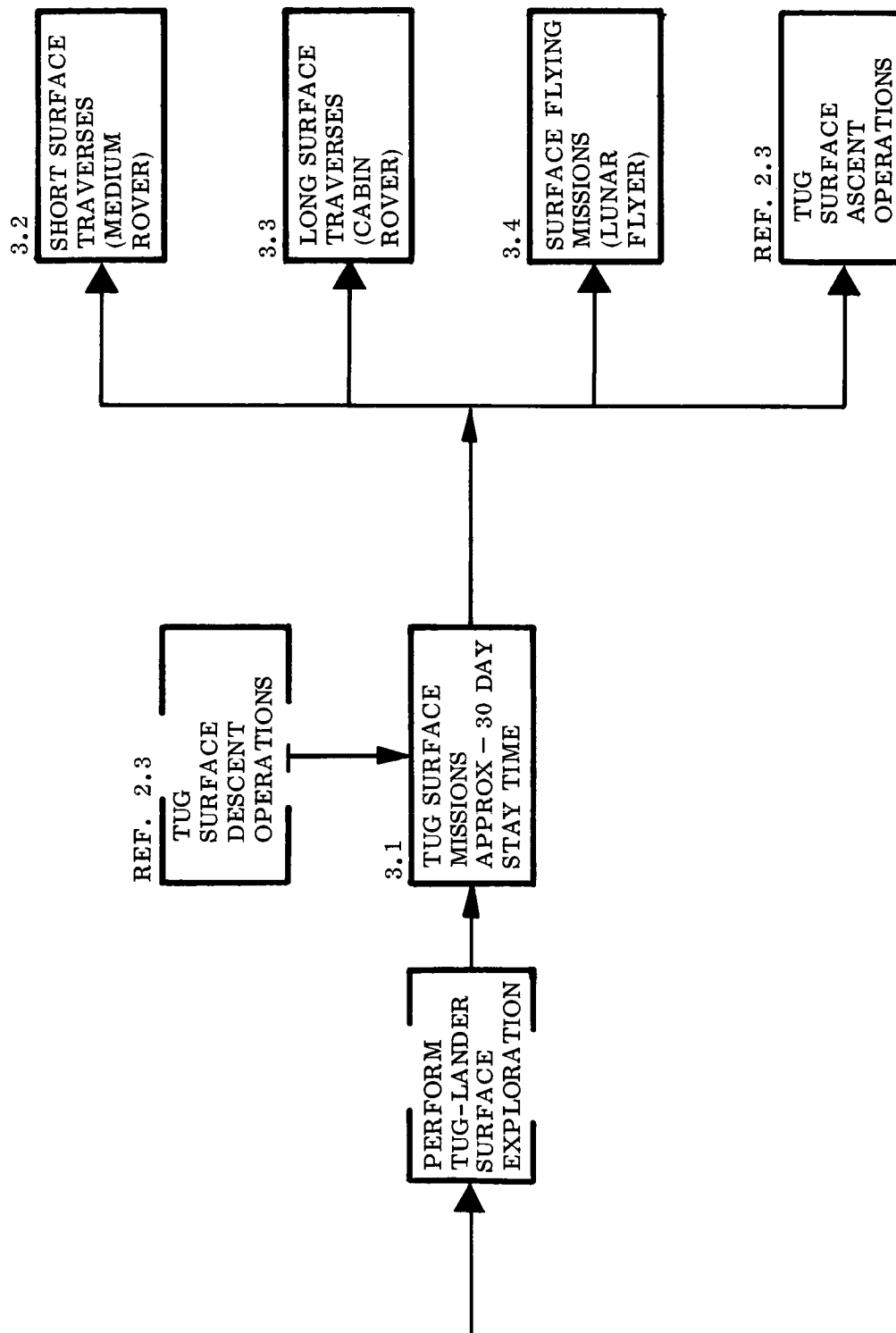


Fig. D-12 Lunar Surface Operations First-Level Functions

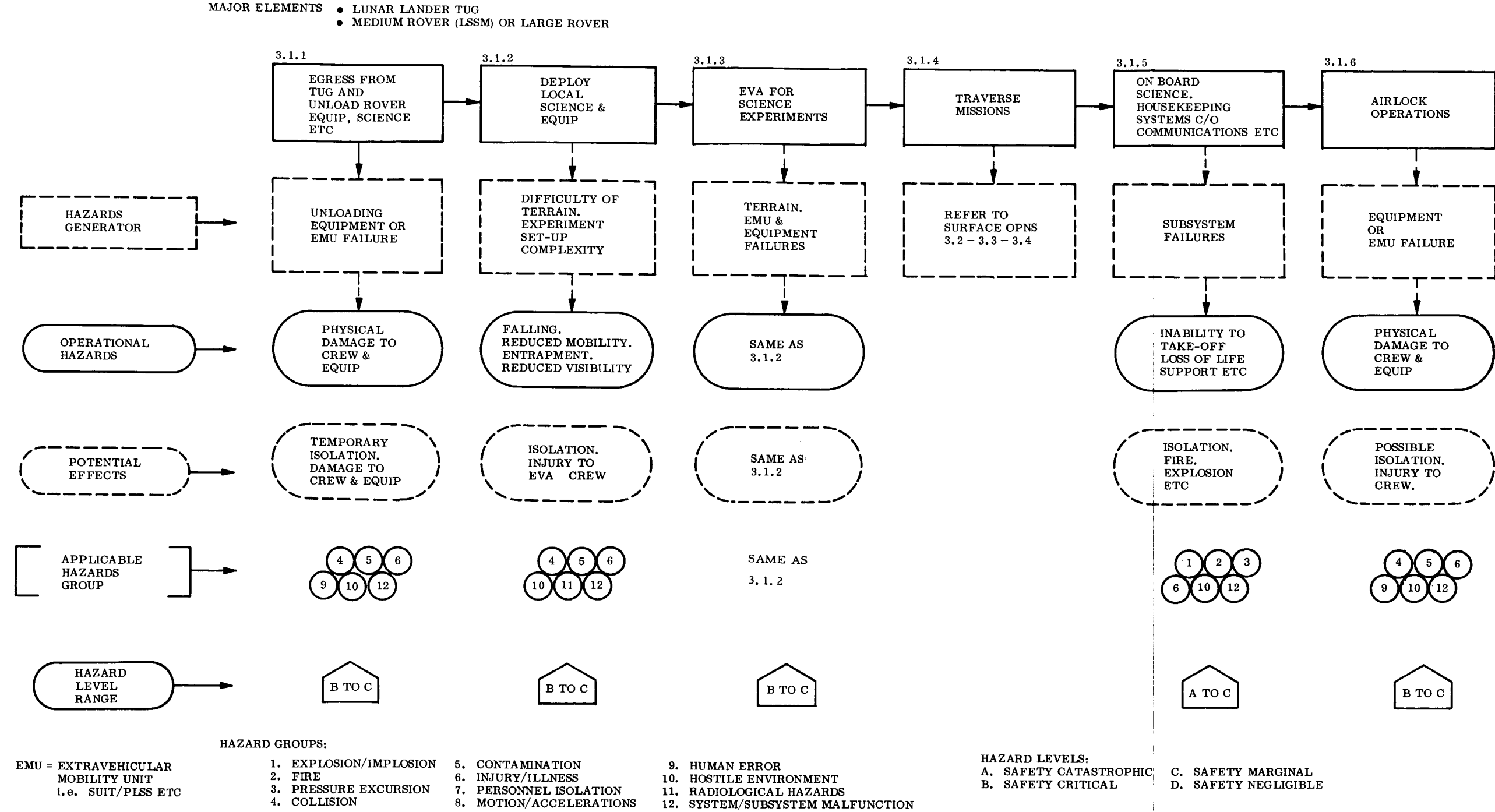
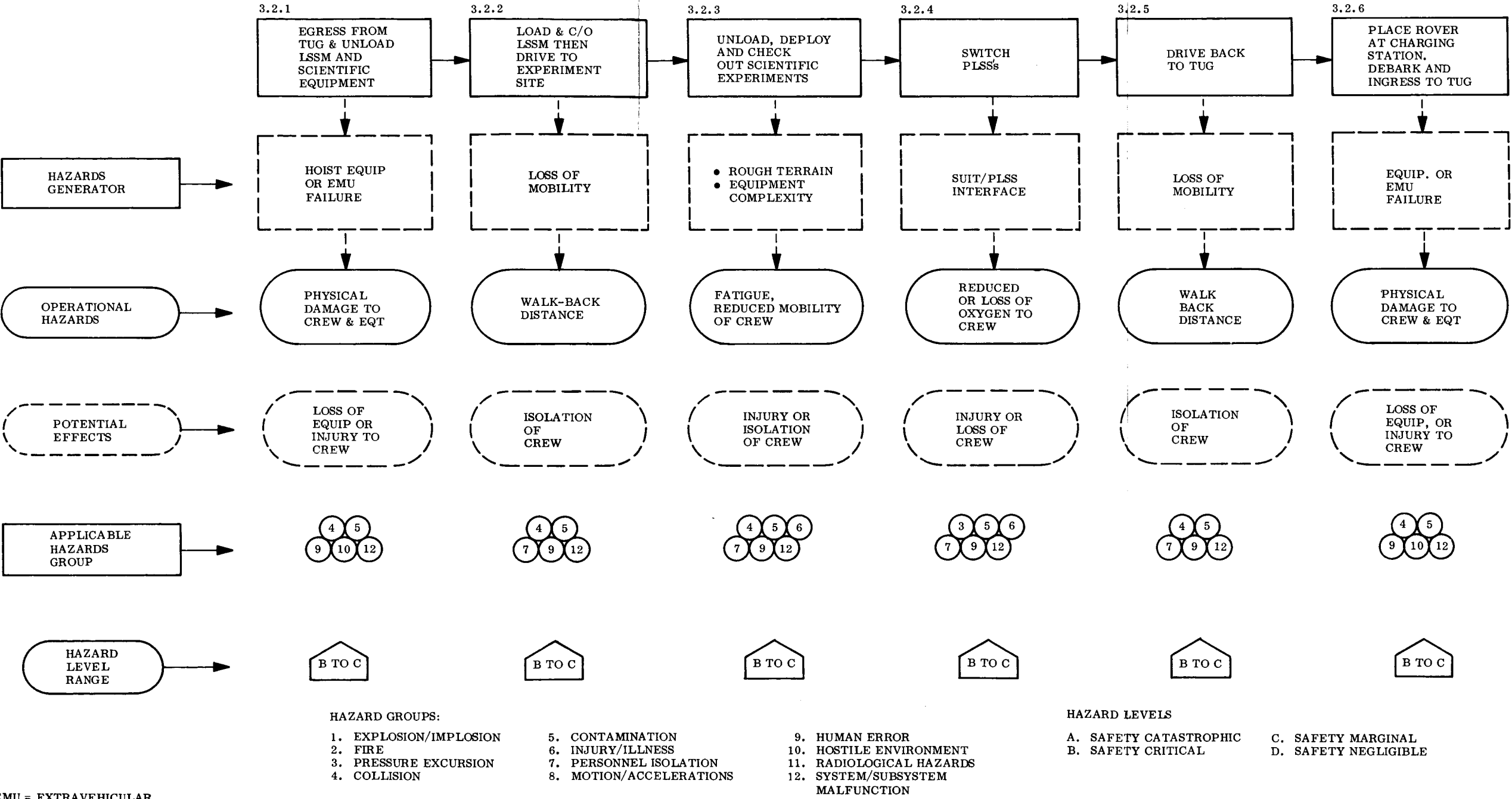


Fig. D-13 Surface Operations - 3.1: Tug Missions - ~30 Days Staytime

MAJOR ELEMENTS

- LUNAR LANDER TUG
- MEDIUM ROVER (LSSM)



EMU = EXTRAVEHICULAR
MOBILITY UNIT
i.e. SUIT/PLSS ETC.

Fig. D-14 Surface Operations - 3.2:
Short Traverses

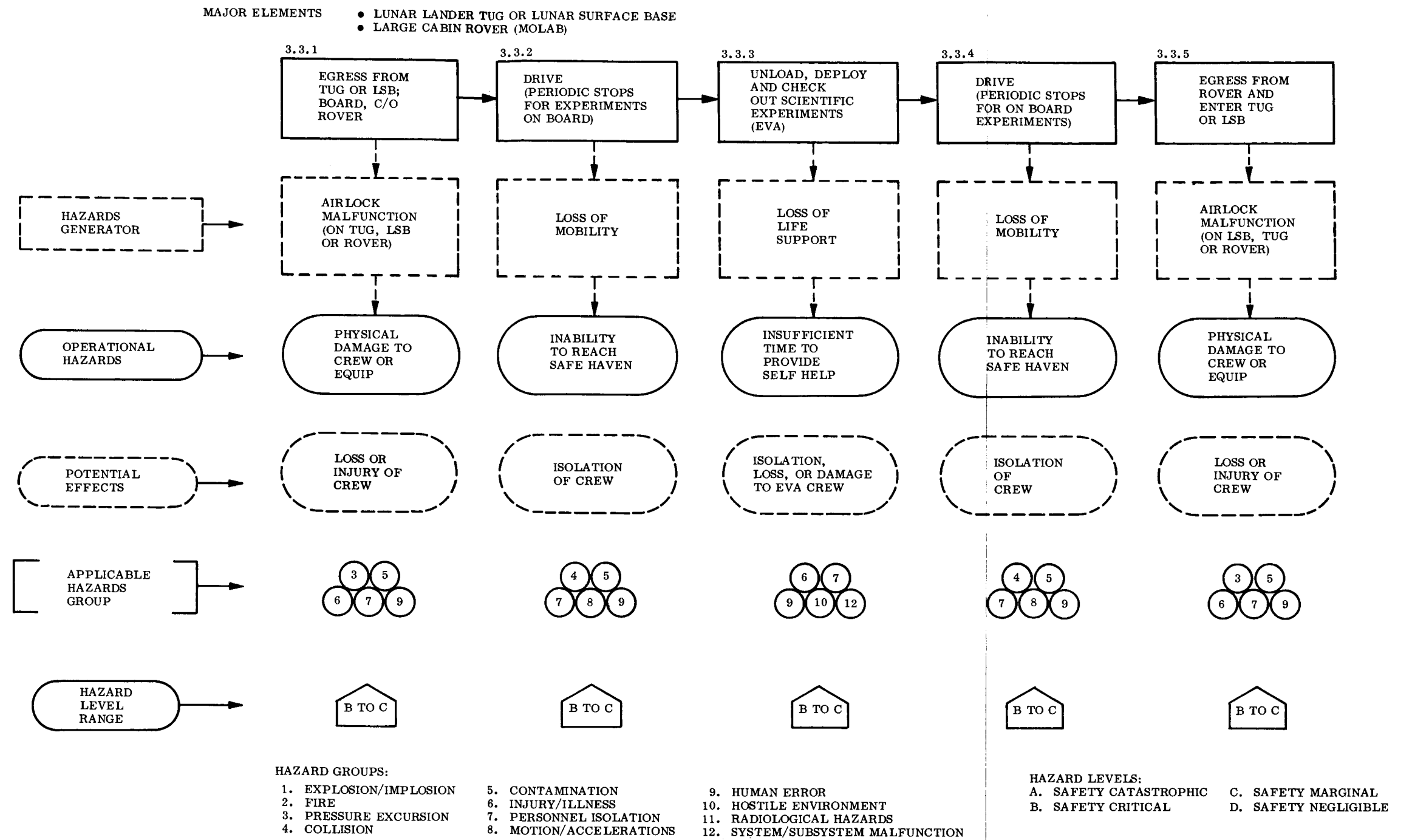


Fig. D-15 Surface Operations - 3.3:
Long Traverses

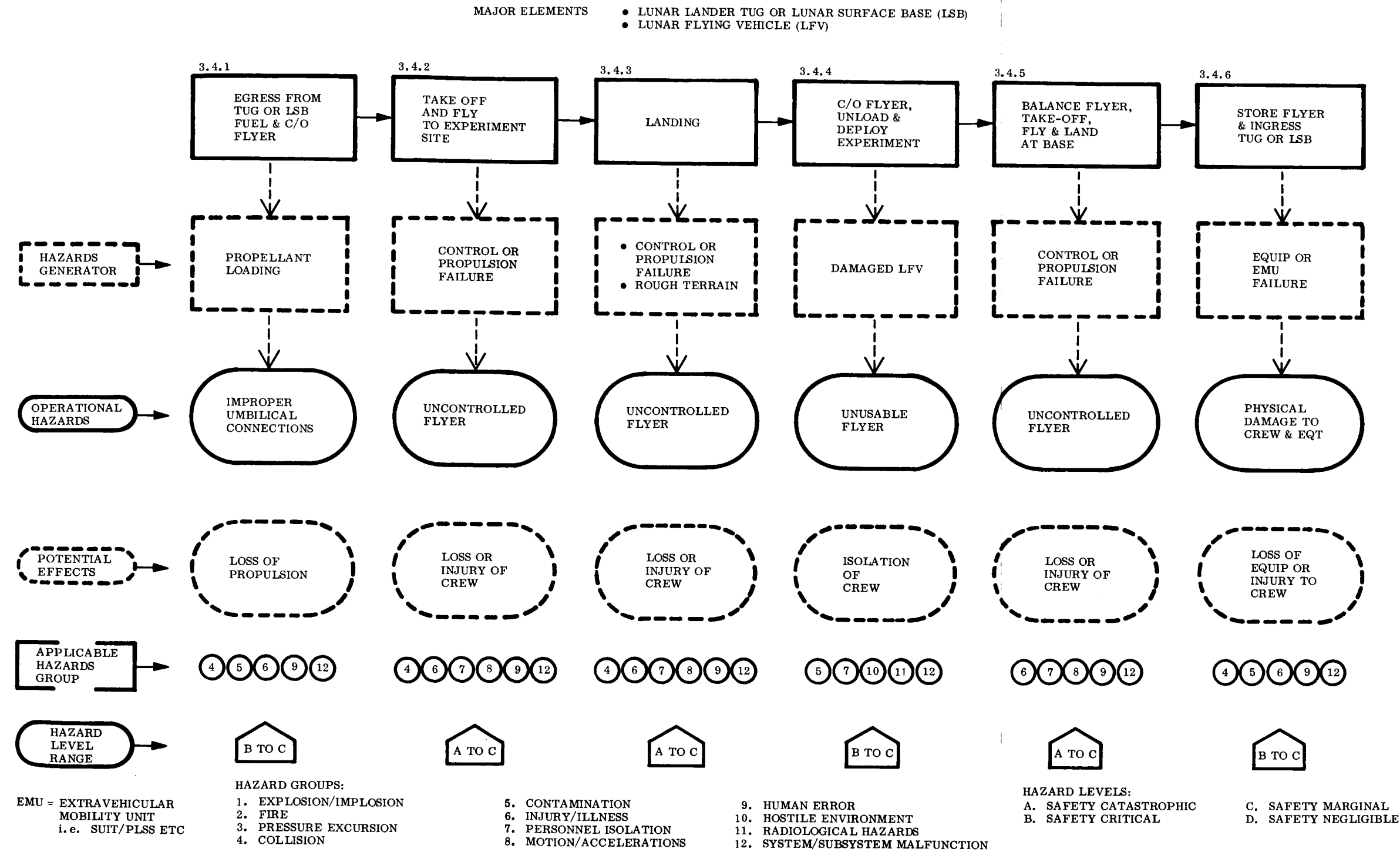


Fig. D-16 Surface Operations - 3.4: Flying Missions

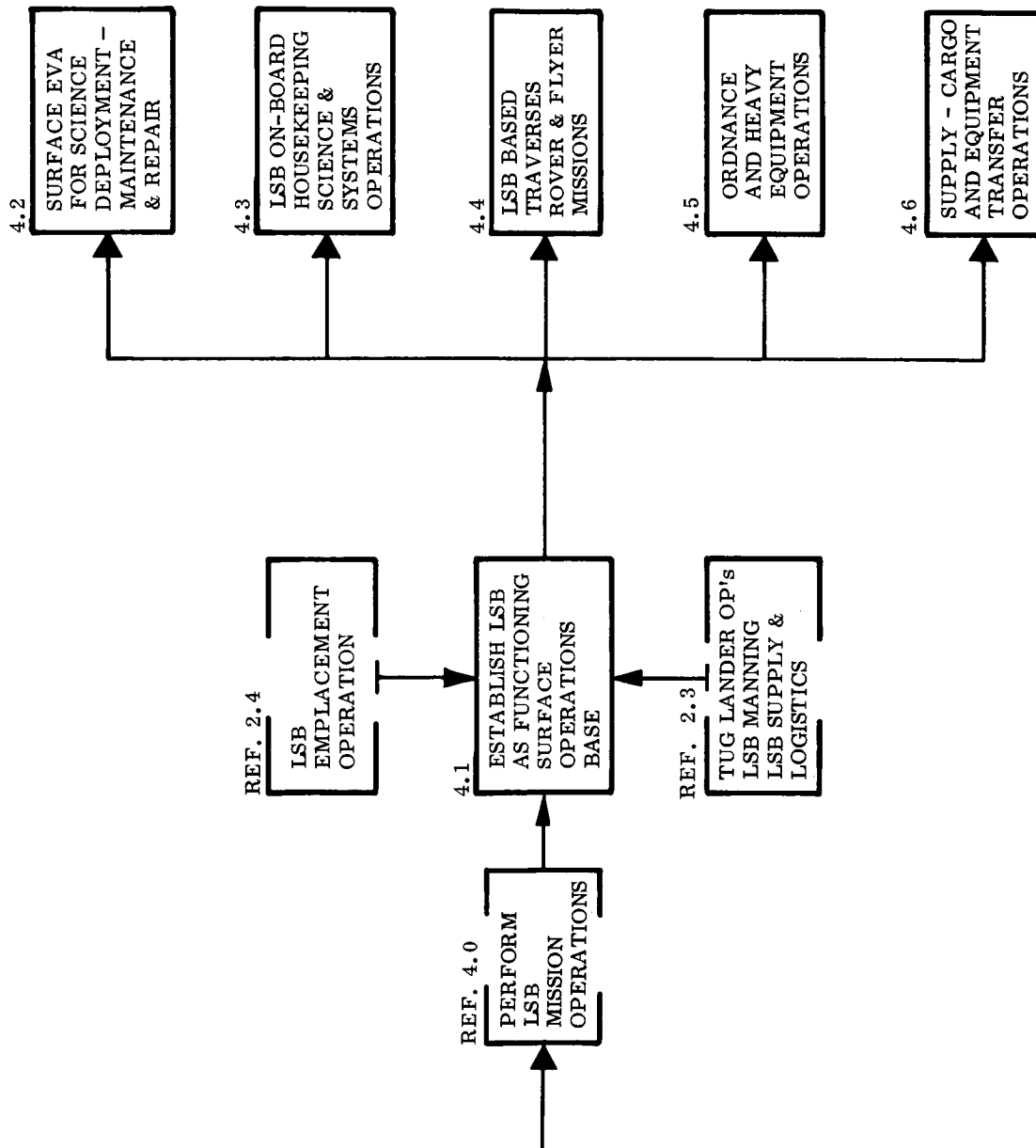
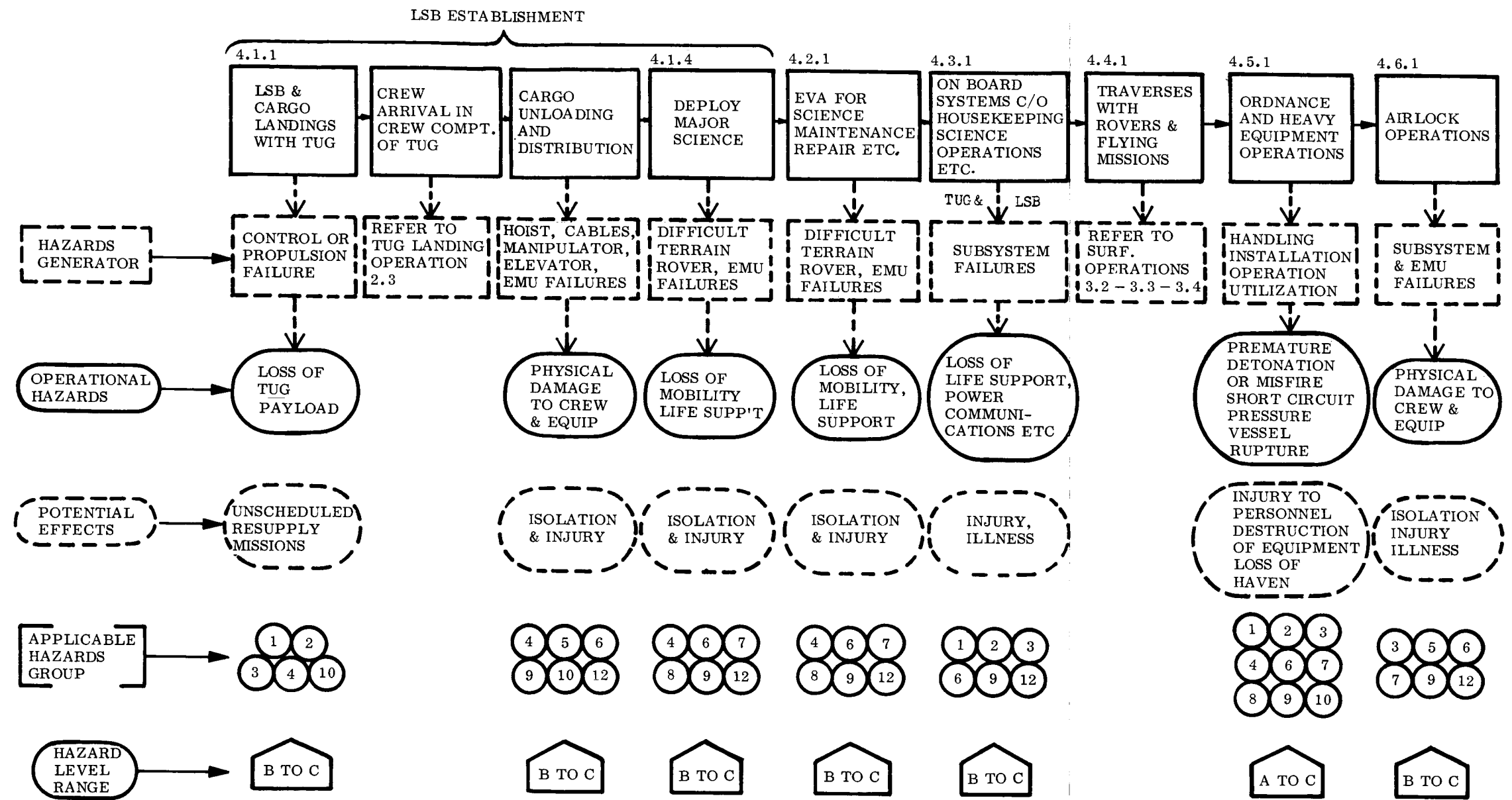


Fig. D-17 Lunar Surface Base Operations First-Level Functions

- LUNAR SURFACE BASE (LSB)
- LUNAR LANDER TUG (LLT) PLUS CREW COMPARTMENT (CC)
- ROVING VEHICLES & FLYING VEHICLES
- MAJOR SCIENCE



EMU = EXTRAVEHICULAR
MOBILITY UNIT
i.e. SUIT/PLSS ETC

HAZARD GROUPS:

1. EXPLOSION/IMPLOSION
2. FIRE
3. PRESSURE EXCURSION
4. COLLISION

5. CONTAMINATION
6. INJURY/ILLNESS
7. PERSONNEL ISOLATION
8. MOTION/ACCELERATIONS

9. HUMAN ERROR
10. HOSTILE ENVIRONMENT
11. RADIOLOGICAL HAZARDS
12. **SYSTEM/SUBSYSTEM MALFUNCTION**

HAZARD LEVELS

- A. SAFETY CATASTROPHIC
B. SAFETY CRITICAL
C. SAFETY MARGINAL
D. SAFETY NEGLIGIBLE

Fig. D-18 Surface Operations - 4.1:
Lunar Surface Base

SUPPLEMENTAL DATA REPORT NO. 1
A STUDY TO EVALUATE RADIATION EXPOSURE OF THE
ORBITING LUNAR STATION AND THE LUNAR SURFACE
RELATED TO REUSABLE NUCLEAR SHUTTLE OPERATIONS

1. STUDY OBJECTIVES AND APPROACH

This study was conducted to determine the radiation environment created by a Reusable Nuclear Shuttle (RNS) in performing its normal mission functions while in the lunar vicinity, and to evaluate the impact of that environment on the Orbiting Lunar Station (OLS) or lunar surface operations. Trajectory data and the nuclear engine (NERVA) operating history were taken from data developed during the Nuclear Flight Systems Definition Study, Phase II (NAS 8-24715) and reported in Ref. 1. Although operating characteristics of the NERVA engine have recently been revised in regards to startup, shutdown, and cool-down, the changes will have only secondary effects on trajectory behavior and little or no effect on the radiation environment.

The OLS is assumed to be in 60 n.mi. circular polar orbit. The RNS on lunar arrival will be required only to inject into the reference orbit in the near vicinity of the OLS. All payload transfers to and from the RNS will be conducted by other space elements (tugs, etc.). Residence time of the RNS in lunar orbit can vary from about 4 days to 30 days during which time no operation of the NERVA engine will occur. RNS coplanar lunar arrival opportunities occur twice each lunar month although normal trip frequency would probably not exceed one every 54.6 days.

Most lunar departures will require some out-of-plane maneuvers in order to permit coplanar arrival at Earth. These departures will normally be performed using a 3-burn maneuver to minimize energy requirements, although single burn departures may be selected if the total plane change requirement is less than 20 degrees.

2. RADIATION ENVIRONMENT CREATED BY THE NUCLEAR ENGINE

2.1 OPERATIONAL ENVIRONMENT

The most severe radiation environment will exist during periods in which the NERVA reactor is operating when both neutron and gamma radiation will be present. The intensity will depend on the reactor power level, distance from the source, and intervening mass such as engine shielding or components. From Figure 1 it can be seen that significant dose rates will be encountered hundreds of miles away in the vacuum of space during periods of full power (1575 mw) operation.

The effect of shielding and scatter from engine and stage hardware on the neutron and gamma dose rates is presented in Figure 2 for a separation distance of 100 feet. For this evaluation the 1969 CRAM (Common Radiation Analysis Model) as given in Ref. 2 was used. The sharp reduction in dose rate in the forward sector of the vehicle ($0^\circ - 15^\circ$) is related to the engine internal shield. Neutron dose rates assumed an RBE (radiobiological equivalent) factor of 8. Distance effects can be determined using the inverse square relationship of dose to distance.

2.2 POST OPERATIONAL ENVIRONMENT

When the reactor is shut down and the source of neutrons eliminated, the radiation environment will be considerably diminished, consisting primarily of gamma radiation due to fission product decay in the core. Unlike the operating dose rate, which can be considered constant during periods of constant power operation, the post operational fission product source term is decaying with time with the result that the environment is a function of time after shutdown as well as distance and view angle. In Figure 3 it can be seen that 1 hour after shutdown the fission product gamma dose rate at 5000 meters (2.7 nm) is 4×10^{-5} R/sec (0.144 R/hr), while for the operating engine (see Figure 1) the same dose rate from combined neutron and gamma radiation could

be received as far away as 150 n.mi. Furthermore, because the fission product source is diminishing with time (see Figure 4) one would have to remain about 4200 meters from the engine for 1 hour to receive 0.144 Rem (see Figure 5). For the first few days following shutdown the fission product source term will be dominated by the short-lived fission products from the last burn. For longer decay times the buildup of greater inventories of longer-lived fission products related to multiple burns will become more pronounced as can be seen in Figure 5 for the first and second arrival of the RNS in lunar orbit.

For the analyses the post operational fission product source term was computed following shutdown in lunar orbit for the first lunar mission of the RNS and is shown in Figure 4. These data are representative of the 90° view angle, or maximum dose rate considering only the self-shielding effects of the core itself. Attenuation due to view angle used in the study, again based on Reference (2), is shown in Figure 6. As was done for the operating case, distance attenuation was computed using the inverse square relationship.

3. EFFECT OF DECAY HEAT ON RNS PROPULSIVE MANEUVERS

In addition to the radiation environment caused by the decaying fission products in the engine core, a considerable quantity of heat is released which must be removed to prevent damage to the engine. For example, at the end of shutdown (Scram) for a typical LOI burn the decay heat rate is about 3.7×10^5 Btu/sec which would be sufficient to vaporize core material if a continuous flow of coolant was not provided. After about 325 seconds the rate will have dropped to about 6.8×10^3 Btu/sec and the cooling can be provided at a lower rate, or as is the case, in intermittent pulses. These pulses will continue with diminishing frequency until the decay heat rate is low enough to permit cooling by radiation alone. Current data using 5 Btu/sec as the cut-off would require active cooling for approximately 40 hours following the LOI burn.

The effect of this cooling requirement on the trajectory at lunar orbit arrival is shown in Figure 7 in which the impulse produced by the after cooling is used to provide a portion of the ΔV required for the orbit insertion. While the long pulse-cooling time (in the example only about 12 hours of cool-down impulse were used) will complicate the maneuver from a guidance and control standpoint, it has the advantage of increasing the separation distance between RNS and OLS during the actual reactor operation.

A typical three burn departure maneuver is shown in Figure 8. For this maneuver only the first burn will occur close enough to the OLS or lunar surface to be of concern.

4. RADIATION EXPOSURE TO THE OLS DURING NORMAL RNS LUNAR MISSION OPERATIONS

4.1 LUNAR ORBIT INSERTION

The integrated neutron and gamma dose levels which would be received at the OLS during RNS lunar orbit insertion were evaluated for two conditions; (1) final LOI 10 Km ahead of the OLS, and (2) 10 Km behind the OLS.

During the main engine burn the separation distance (RNS to OLS) and view angle for both cases are virtually the same and are presented in Figure 9. The total dose delivered to the OLS during the period from startup to scram was computed to be 0.194 mRem, of which 0.144 mRem was attributable to neutrons and 0.050 mRem to gamma radiation.

Almost coincident with shutdown the view angle becomes less than 15° for both cases and remains so during most of the cooldown insertion. Thus, even though the RNS - OLS distance is diminishing, the protection provided by the engine internal shield effectively eliminates any radiation problem at the OLS. The variations in separation distance and view angle for the case in which final LOI occurs 10 Km behind the OLS, and the view angle for the alternate case, are shown in Figure 10.

For arrival 10 Km behind the OLS a total fission product gamma dose of 7.03 mRem, roughly 36 times the dose received during the main burn, will be received at the OLS. Most of this dose will be delivered during the time interval from about 38,000 to 39,000 seconds when the RNS is making a close passage with the OLS and the view angle is in the 60° to 140° range.

For the alternate arrival condition, 10 Km ahead of the OLS, the RNS would always remain oriented such that the OLS is within the engine shield cone, effectively eliminating any measurable dose at the OLS. This case also eliminated the close passage problem encountered in the other example.

Increasing the separation distance at final LOI would have little effect on the dose if arrival behind the OLS is selected unless the distance was increased to the point that the close passage was eliminated. It can reasonably be concluded then that unless mission conditions dictate otherwise, arrival of the RNS ahead of the OLS would be selected.

4.2 LUNAR ORBIT DEPARTURE

The lunar orbit departure operation may be accomplished using a single burn or a 3-burn maneuver, depending on the amount of plane change required to satisfy the trans-earth injection (TEI) conditions. During the 3-burn departure the second and third burns will occur at such high altitudes (see Figure 8) that no effective dose will be received at the OLS.

The neutron and gamma dose received at the OLS was evaluated for three departure startup conditions; RNS 5.4 n.mi. behind the OLS, RNS 5.4 n.mi. ahead of the OLS and RNS 20 n.mi. ahead of the OLS.

Separation distances and view angles for startup 5.4 n.mi. (10 Km) ahead of and 5.4 n.mi. behind the OLS are presented in Figures 11 and 12. Startup 20 n.mi. ahead would be similar to the 5.4 n.mi. ahead case except that the distances would be greater by about 15 n.mi.

Integrated neutron and gamma doses at the OLS for these cases will be:

Position at Startup	Neutron Dose	Gamma Dose
5.4 n.mi. behind OLS	42.9 Rem	5.41 Rem
5.4 n.mi. ahead of OLS	2.52 Rem	.139 Rem
20 n.mi. ahead of OLS	.266 Rem	.015 Rem

The high dose for the case where startup occurs 10 Km behind the OLS results from the very close OLS passage (about 0.29 n.mi.) during the reactor operating period. The benefits of even modest increases in separation distance are readily apparent from the other two cases evaluated.

The high neutron and gamma doses during engine operation for startup behind the OLS could be eliminated if the initial distance was increased to about 30 n.mi., however, a close OLS passage when fission product gamma rates are near maximum would still be required. Additionally, the risk of collision during the flyby would also represent an undesirable hazard.

The analyses support the conclusion that if startup near the OLS was required, a position ahead of it in orbit would be favored. A distance of at least 20 n.mi. would be desirable. On the other hand, since the RNS requires no direct OLS support for the TEI maneuver a more desirable condition for startup would be with the RNS beyond the lunar horizon (about 680 n.mi. for 60 n.mi. orbit altitudes) such that the engine burn could not be seen at the OLS and none of the low altitude operation would occur near the OLS.

4.3 RADIATION EXPOSURE DURING RNS RESIDENCE IN LUNAR ORBIT

On arriving at the Moon the nuclear shuttle will be divested of its outbound payload by lunar tugs or using propulsion units in the payload itself. Sometime prior to departure an Earth-return payload will be delivered to the RNS and docked to it. At all other times, the RNS will simply stand by in orbit waiting either to receive a payload or for the desired TEI opportunity to occur. If the RNS is near other space elements, it can be commanded to

maintain a "nose-on" attitude toward the particular element to preclude any dose to crews or equipment, thus eliminating any accumulation of radiation dose during normal RNS standby operations. It would be parked during such standby periods sufficiently distant from the OLS to permit unrestricted arrivals and departures of lunar tugs or other vehicles.

Except in the event of an RNS system malfunction no hazards would be associated with this standby period.

5. RADIATION EXPOSURE TO LUNAR SURFACE DURING RNS ARRIVAL OR DEPARTURE

Radiation exposure to men or installations on the lunar surface along the incoming trajectory trace could occur during periods of nuclear engine operation for the lunar arrival and departure burns. The most severe arrival situation would involve a single burn LOI maneuver in which a minimum recovery of after-cooling impulse was planned. This type insertion would result in the lowest altitude during the burn. For evaluation, an incoming trajectory was selected for which no after-cooling impulse recovery was employed. The approach is represented pictorially in Figure 13. RNS altitude at the beginning of steady-state operation is about 85 n.mi. Neutron and gamma doses delivered to various positions along the surface track were evaluated using the separation distance and view angle data given in Figures 14 and 15.

The neutron and gamma doses received along the ground track reach maximums of about 23.5 and 3.0 mRem at position 3, vertically below the RNS at shutdown (see Figure 16). Uprange positions 1 and 2 benefit from the change in view angle after the overflight while downrange positions 4 and 5 benefit from increased range and even more important are hidden by the lunar horizon during the early portion of the burn with position 5 not coming into view until shutdown is initiated.

Normal LOI burns would start up at altitudes of about 125 n.mi. and shut down at about 95 n.mi. for which case the dose at the surface would be reduced to perhaps one-third to one-half the values for the low altitude approach. In any event surface doses from the LOI or TEI burns would cause no concern for ground positions unless experiments with sensitive measurement instruments were involved in which case it may be necessary to provide some form of protection for these systems if they are situated in locations which could be beneath the RNS during periods of full-power operation.

The most severe dose to the surface would probably occur for a single burn lunar departure with the RNS carrying maximum payload. This case was not evaluated due to the lack of suitable trajectory information on which to base the analyses. Burn times of 300 to 400 seconds would be required most of which would occur at or near 60 n.mi. altitude. The picture would not be too unlike the low altitude arrival with the exception that altitudes and relative velocities during the full-power interval would be lower suggesting higher peak doses. While the resulting conditions on the surface should not be considered as indicative of a problem, they should be considered in planning surface activities if nuclear lunar shuttles are employed.

6. EFFECT OF NERVA EXHAUST PLUME ON ORBITING LUNAR ELEMENTS

During nuclear engine operation fission products can be ejected from the core either in particulate matter produced by corrosion of the fuel elements or as gaseous material diffusing through the fuel matrix. Since these fission products will be carried along in the exhaust, they could theoretically represent a hazard to systems such as the OLS or Lunar Tug which subsequently pass through the expanded exhaust plume or to the RNS itself which during retro maneuvers will sweep through a portion of its own plume.

Little is known either about the size and mass distribution of the NERVA exhaust plume or the concentration of fission products within it, however, Westinghouse Astronuclear Laboratory has conducted a preliminary evaluation of

the impact of radiation sources in the plume on manned orbital facilities (Ref. 3). From their analyses, which were intentionally conservative, it appears that no radiological hazard to men or equipment will result if passage through the plume occurs after it has achieved its full expansion. Situations in which only partial expansion has taken place when a manned system enters the plume, such as would occur for an RNS departing lunar orbit from a position ahead of the OLS, have not been examined to sufficient depth to draw valid conclusions, however, preliminary assessment for RNS startup 20 n.mi. or more ahead of the OLS suggest the dose levels from the plume sources at the OLS will be sufficiently reduced to eliminate it as a serious source of radiation exposure.

A possible exposure-producing situation is one which might arise from the capture of radioactive particulate matter by the exterior surfaces of the OLS or other manned vehicle systems. Subsequent EVA activities involving contact with the contaminated surfaces could result in a transfer of particles to the crewman's space suit or equipment and a potential direct skin contact or ingestion if the suit were handled after return to the spacecraft cabin. While a theoretical exposure route can be postulated, the potential for significant exposures is considered too remote to be of concern since the particulate matter would be very small containing an insufficient fission product inventory to be hazardous even if a large number of such particles were involved. However, on early missions involving the RNS it would be desirable to perform inspections of surfaces exposed to the NERVA plume to determine how much contamination, if any, could be expected.

Catastrophic failures such as loss of coolant to the engine causing destructive disassembly of the reactor could result in hazardous conditions at or near the OLS or other space elements. Depending on the location and concentration of the radioactive debris it is conceivable that manned activities at the OLS might have to be restricted or discontinued until sufficient dispersment of the debris had taken place. Steps are being taken in the NERVA and nuclear shuttle designs to reduce such accidents to incredibility, however,

procedural safeguards including methods for detection and evaluation covering such contingencies would be desirable.

7. OFF-NOMINAL RNS OPERATIONS AND THEIR HAZARD POTENTIAL

Some consideration should be given to the possibility of the RNS operating in an off-nominal manner and what impact such operations might have on the safety of the RNS or other orbiting space elements. For convenience off-optimum operations will be constrained to those operations which result from human error or system malfunctions which do not result in mission abort. Three conditions were considered which fall into this class: (1) lunar approach guidance errors which cause low altitude LOI burn and/or operation close to the OLS, (2) guidance errors during the pulse cooling orbit insertion which could threaten the OLS with collision or close passage radiation exposure and (3) reductions in thrust at LOI which could alter burn duration and location relative to the OLS with final orbit insertion in other than the intended orbit.

Approach Guidance Errors. Approach asymptote errors would require an adjustment in the scheduled full-power engine operation at LOI and if the error was on the low altitude side, could result in performing the LOI burn close enough to the OLS to be of concern. Off-nominal approaches might be discovered too late to correct, but would be known far enough in advance to permit evaluation of the potential hazard which could result if insertion into the planned orbit was attempted. In the event an unacceptable hazard was predicted, injection into the planned orbit would be abandoned. A delayed LOI burn could be substituted, to provide improved separation and view angle, injecting the RNS into elliptical orbit with later transfer to the OLS orbit. In this manner the radiation hazard to the OLS could be avoided although a performance penalty for the Earth-return leg would be encountered.

Guidance Errors During Pulse Cooling LOI. Guidance errors during the cool-down orbit insertion phase are probably the most likely area where off-nominal operations are apt to be encountered. Such errors could accidentally place the RNS in an orbit which could cause a collision or very close passage with the OLS. Preventing a catastrophic event of this type will require frequent updating of the RNS orbital parameters to insure prompt discovery of such a condition. A small velocity impulse either with the RCS system or a subsequent cooling pulse could be used to avoid a collision. Effect of close passage can be minimized by maintaining a nose-on attitude of the RNS during the period of concern. Initiation of cooling pulses during the close passage can be delayed or commanded early, as appropriate, to avoid thrusting during the passage, or if necessary, a direct opposition of the coolant thrust using the RCS system could be considered if a pulse were mandatory during the close passage time interval.

Reductions in Thrust During LOI Burn. Reductions in thrust may be encountered during the main lunar orbit insertion burn due to malfunctions in either stage or engine systems. If the situation were unanticipated (no prior warning that full thrust could not be achieved), insertion into the planned orbit in a single burn could not be accomplished. Instead, the reduced thrust arrival burn would brake the RNS into elliptical orbit. Near apocenter an idle mode NERVA burn could be used to reduce the pericenter altitude to 60 n.mi. and finally a third burn near pericenter would be required to circularize the orbit. Additional phasing of the RNS in circular orbit might be required after circularization unless the elliptical orbit period was carefully synchronized with the OLS.

In the above case, initiation of the arrival burn would be at the planned distance from the OLS and while the burn time would be increased due to the lower thrust, the reactor power would, in all probability, be proportionally lower, thus reducing the radiation environment at the OLS. As long as care were taken to avoid the need to perform the final circularization burn in an adverse manner (near the OLS and with a bad view angle), no increase in radiation dose at the OLS is anticipated.

If prior knowledge that reduced thrust were to be required is available, the approach asymptote could be adjusted and the burn initiation scheduled so that a single burn LOI could be performed. Again the burn time would increase due to the lower available thrust and while the approach altitude would be lower, the reduced reactor power level would probably preclude any increase in the radiation environment at the OLS.

REFERENCES

1. LMSC/A968223, "Nuclear Flight System Definition Study, Phase II," Final Report Volume II, Sunnyvale, California, 1 May 1970.
2. Aerojet General Corp. RN-S-0551, "Full Flow Flight Engine Common Radiation Analysis Model," Sacramento, California, 1969.
3. WANL, DRM No. 51594, "Preliminary Study on Space Distribution of Fission Products from the NERVA Reactor and Their Potential Hazards," Pittsburgh, Pennsylvania, 26 January 1970.

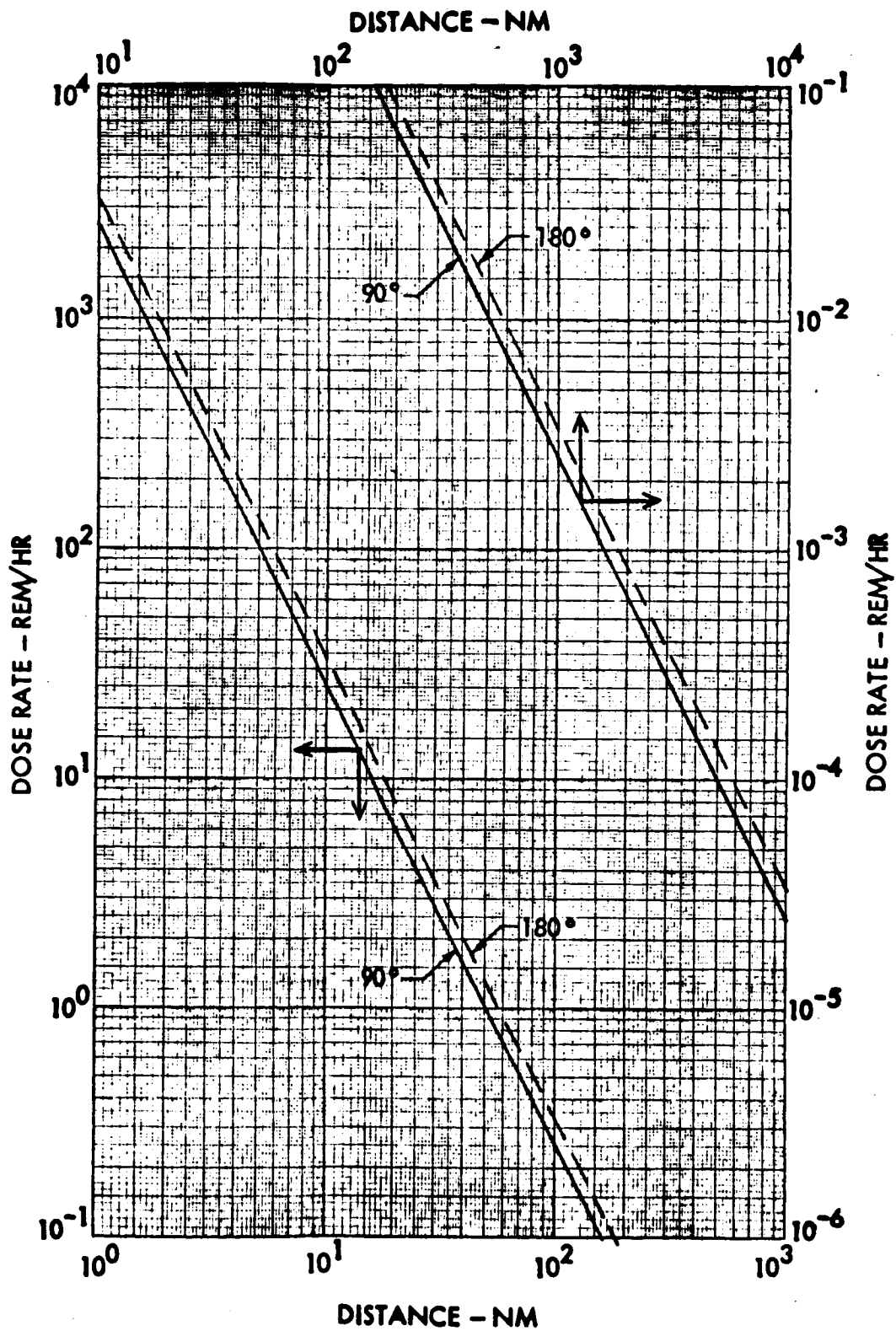


Figure 1 - Dose Rate (Neutron & Gamma) vs Separation Distance From the Operating NERVA Engine

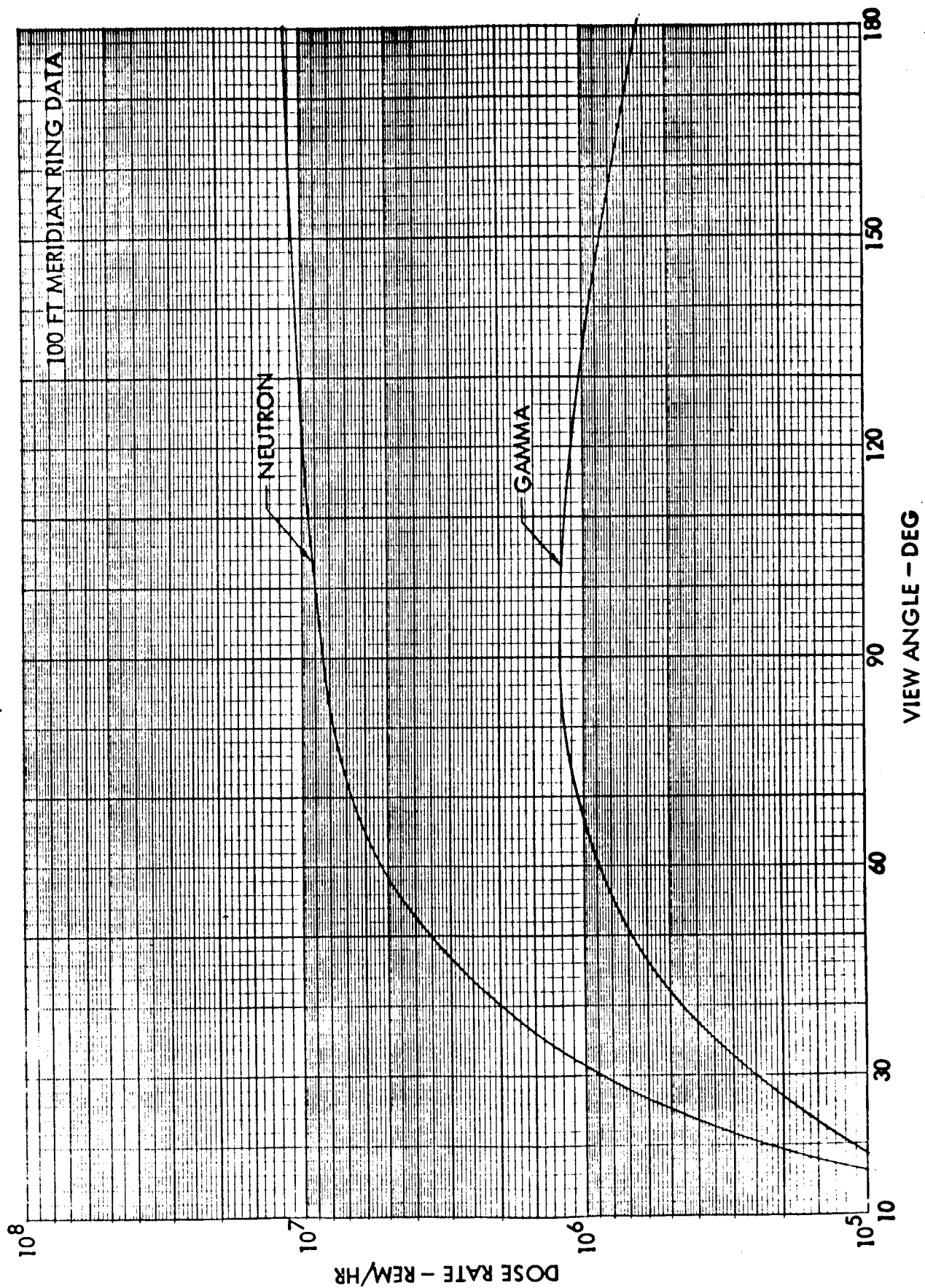


Figure 2 - Dose Rate vs View Angle for the Operating
NERVA - 100 ft Meridian Ring Data

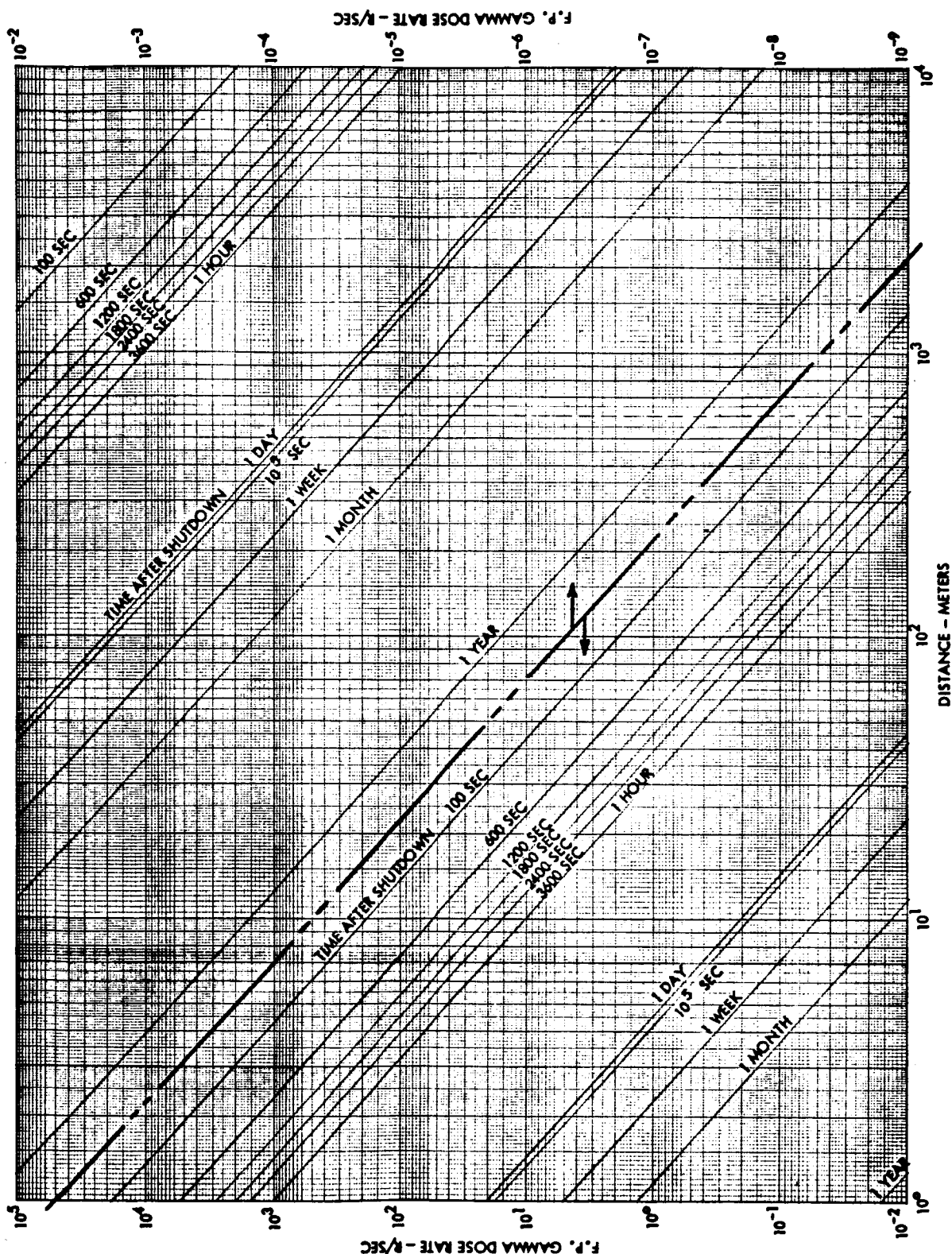


Figure 3 - Fission Product Gamma Dose Rate vs Distance From the Unshielded NERVA Core Following Shutdown in Lunar Orbit

Fig 4

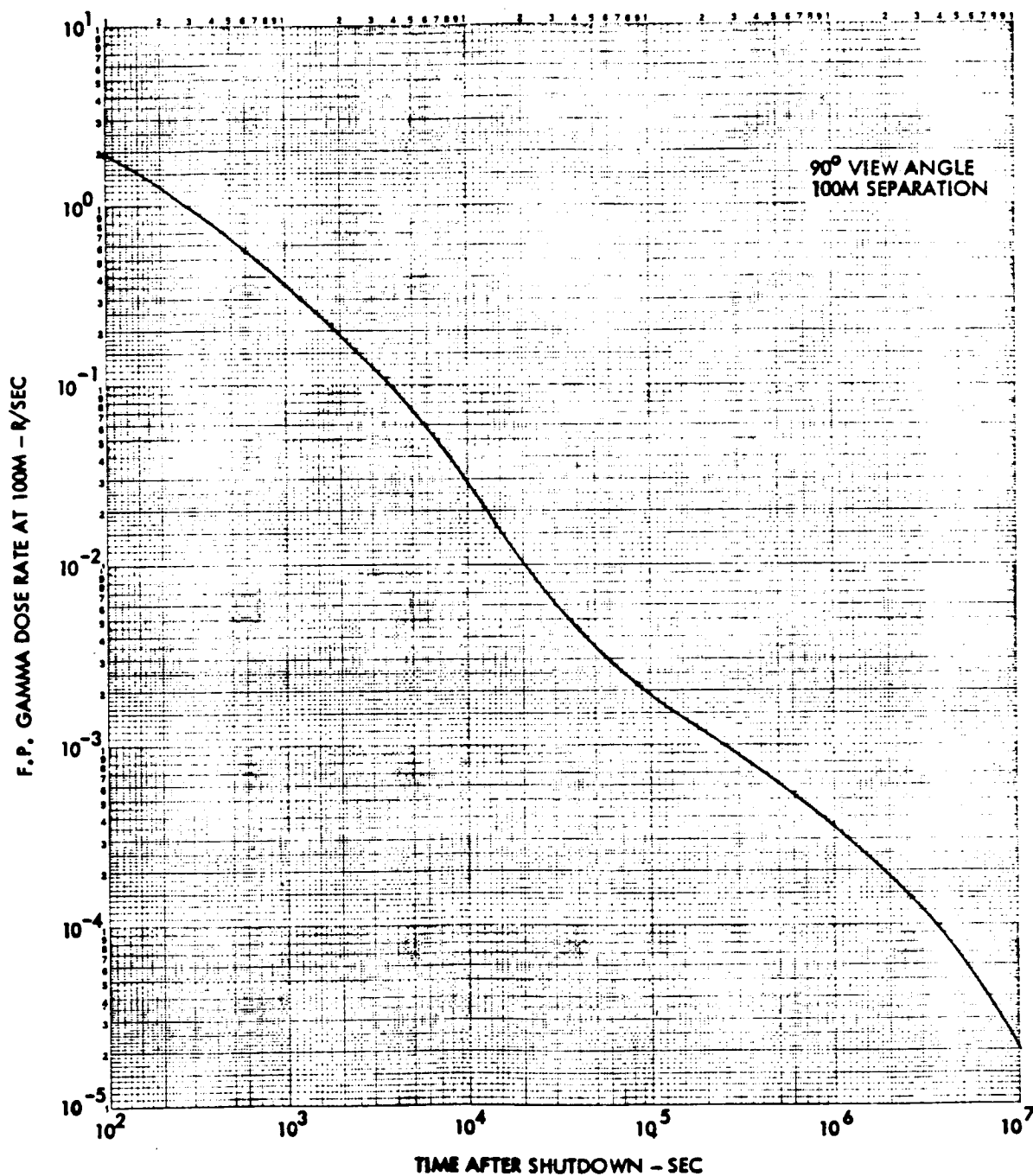


Figure 4 - Fission Product Gamma Dose Rate vs Time After Shutdown
From the NERVA Core - LOI Burn

12-16-70

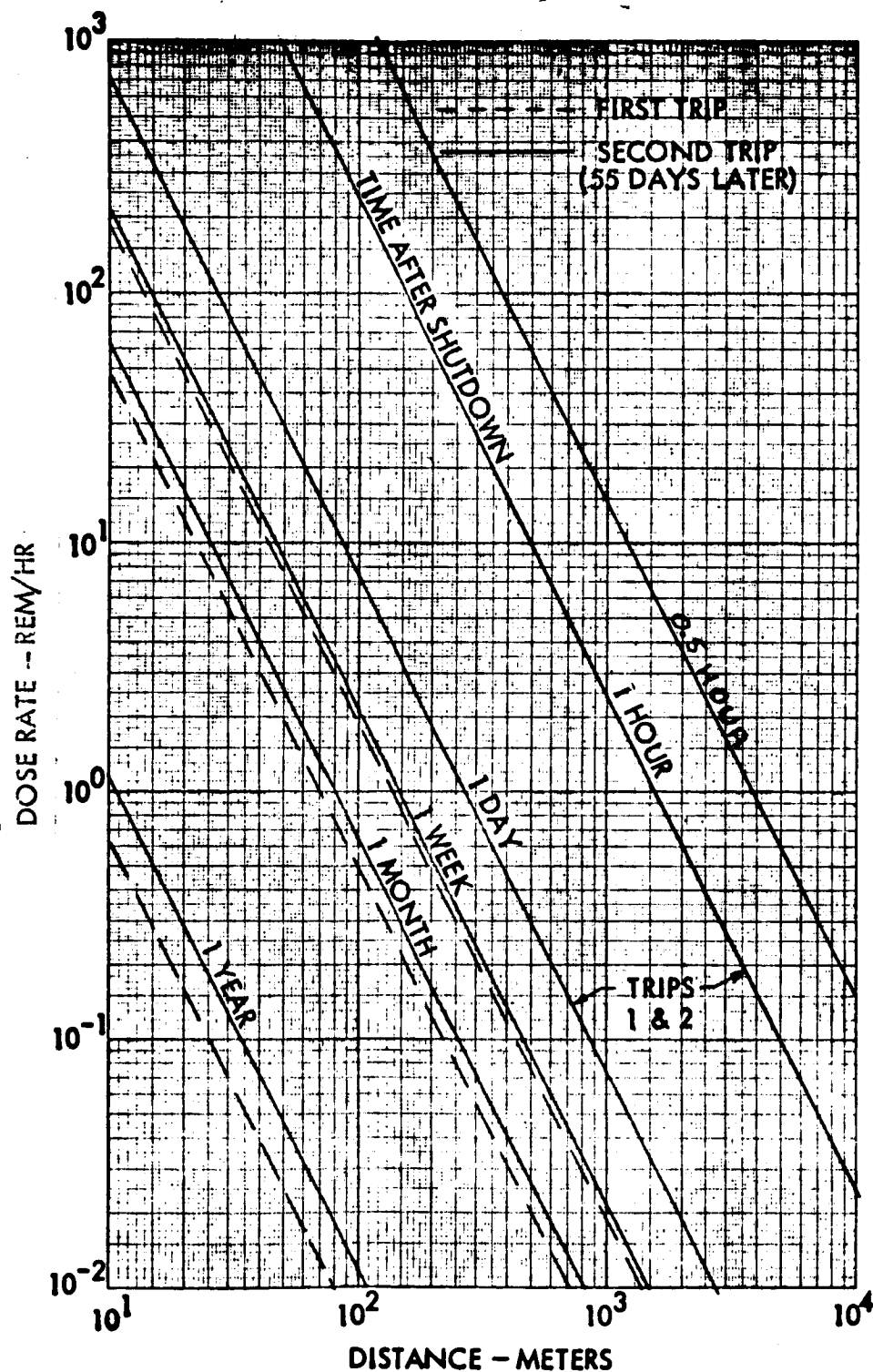


Figure 5 - Fission Product Gamma Dose Rate vs Distance from the Unshielded NERVA Core Following Shutdown

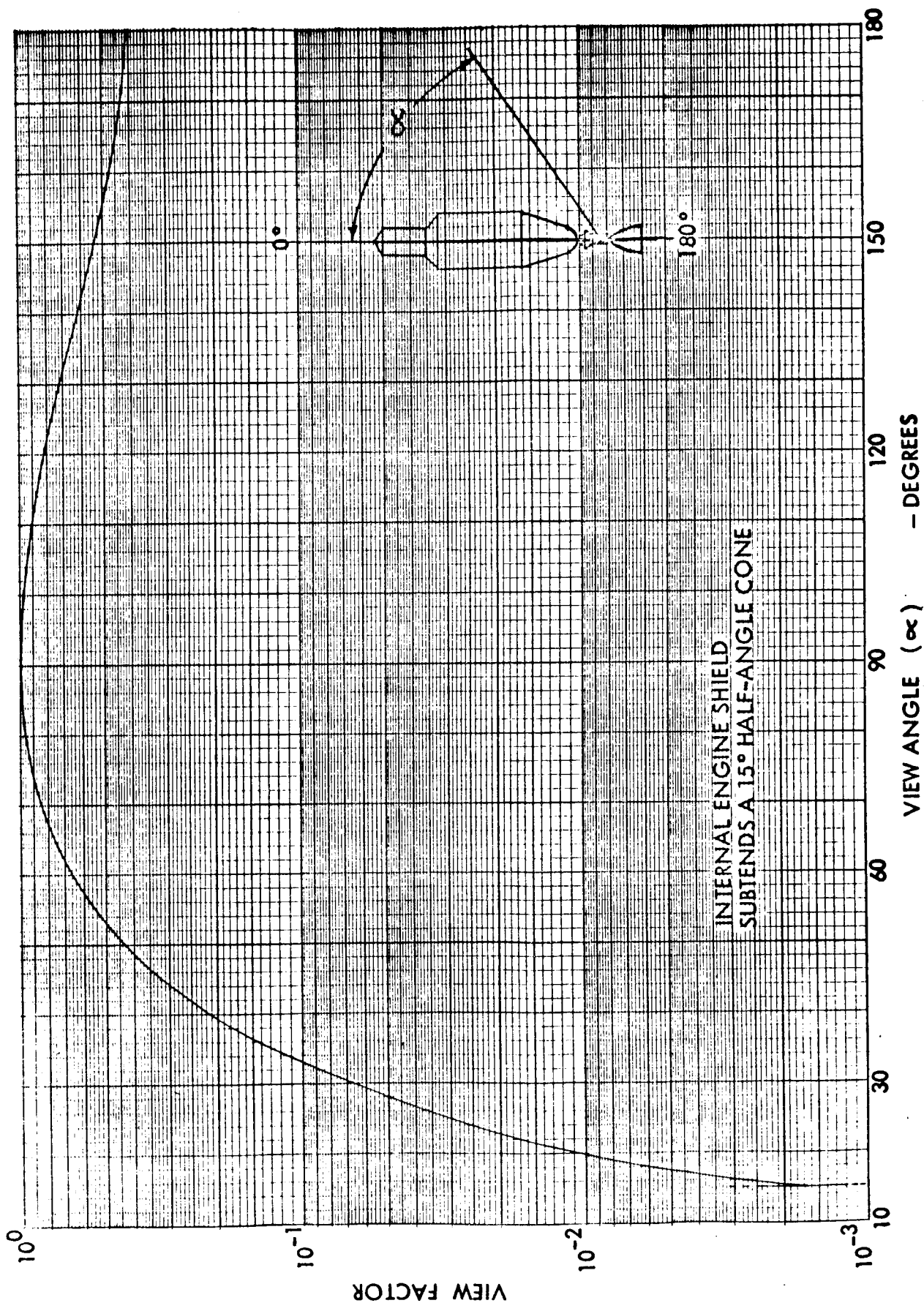
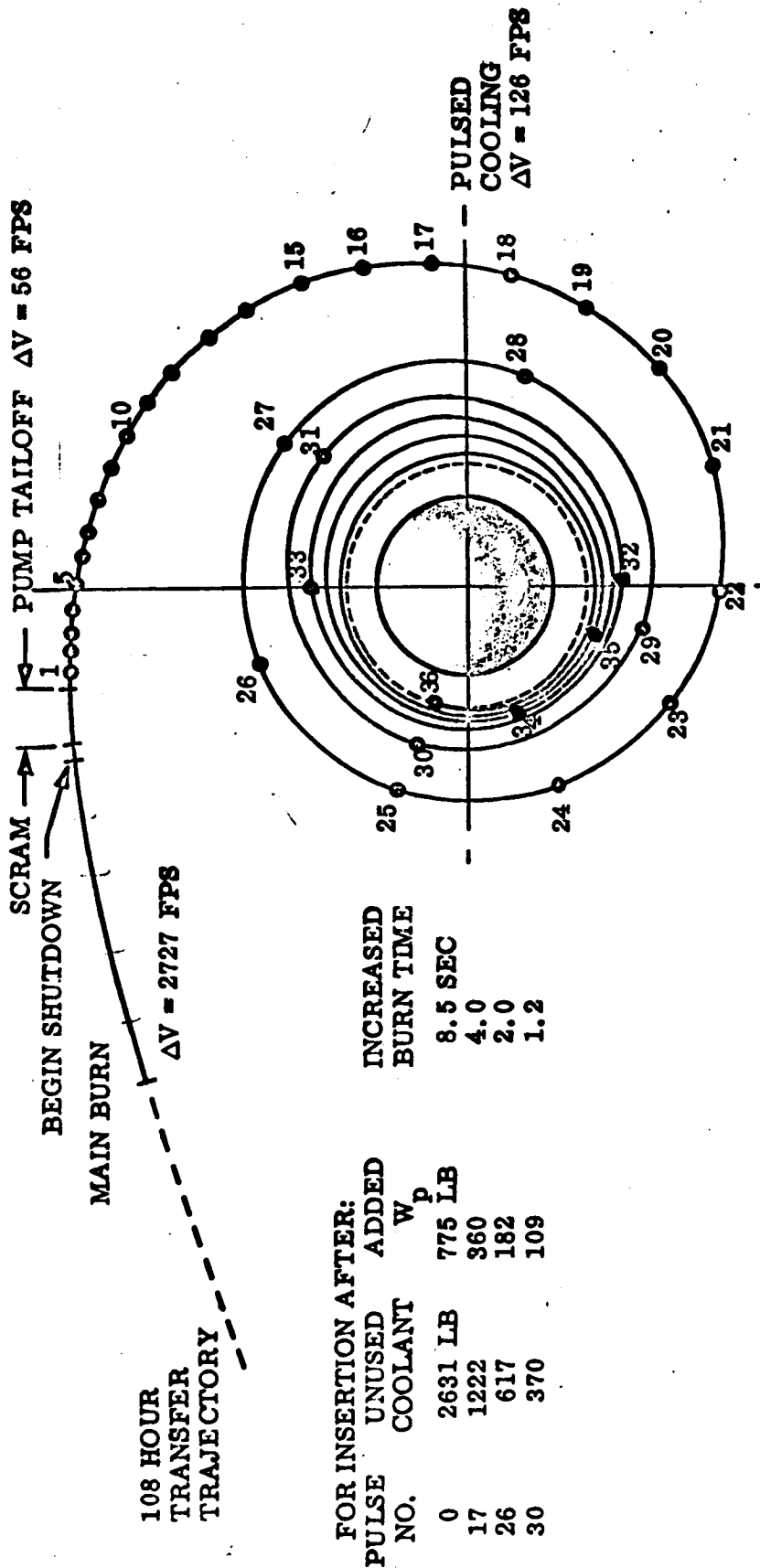


Figure 6 - Effect of View Angle on Fission Product Gamma Dose Rate



PULSE NO.	TIME AFTER SCRAM	REVS	TIME TO NEXT PULSE	% IMPULSE RECOVERED
17	36.3 MIN	0.29	4.5 MIN	54
22	1.1 HR	0.56	9.8	66
26	2.0	0.99	19.7	76
30	3.8	1.85	37.0	85
32	5.1	2.55	1.0 HR	90
33	6.2	3.06	1.4	93
34	7.5	3.73	1.8	95
35	9.3	4.62	2.4	98
36	11.7	5.85	-	100

Figure 7 - Lunar Orbit Insertion Using Cooldown Pulse

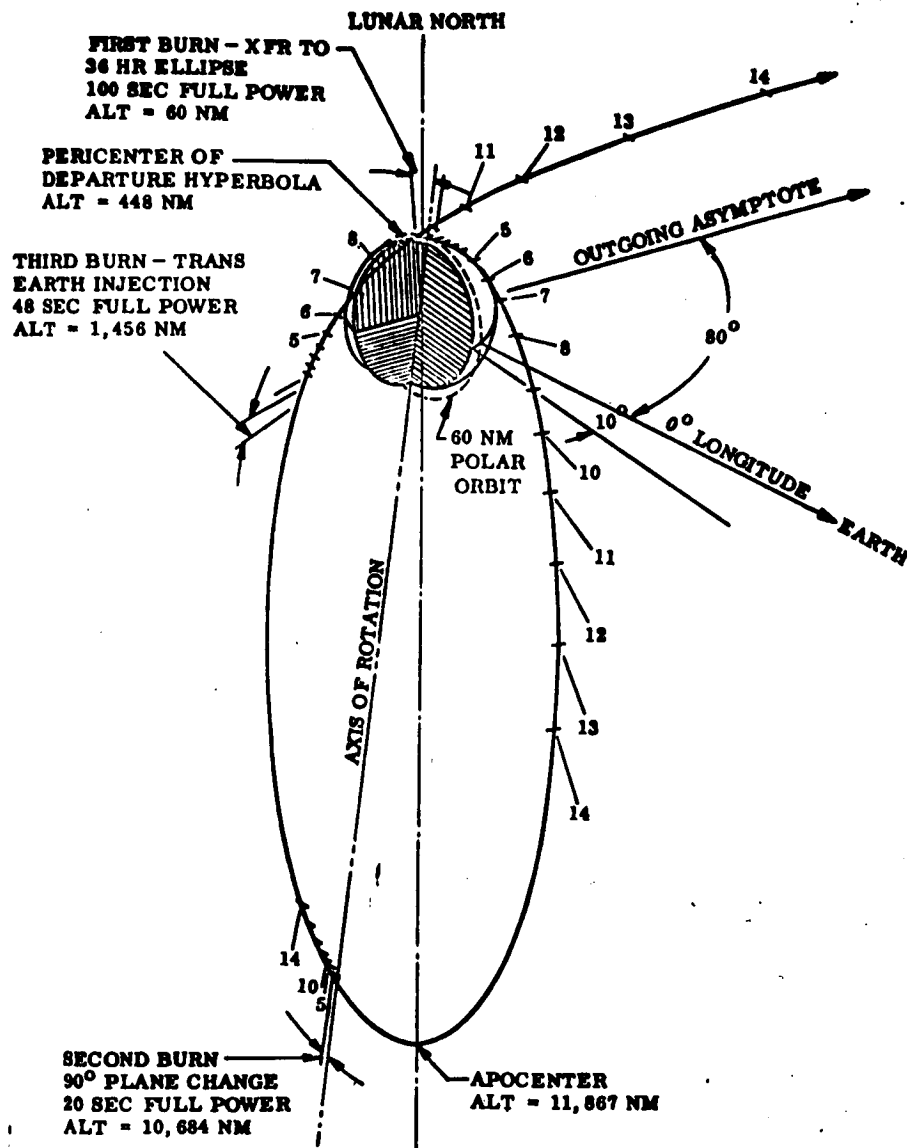


Figure 8 - Typical Three-Burn Lunar Departure With 90° Plane Change

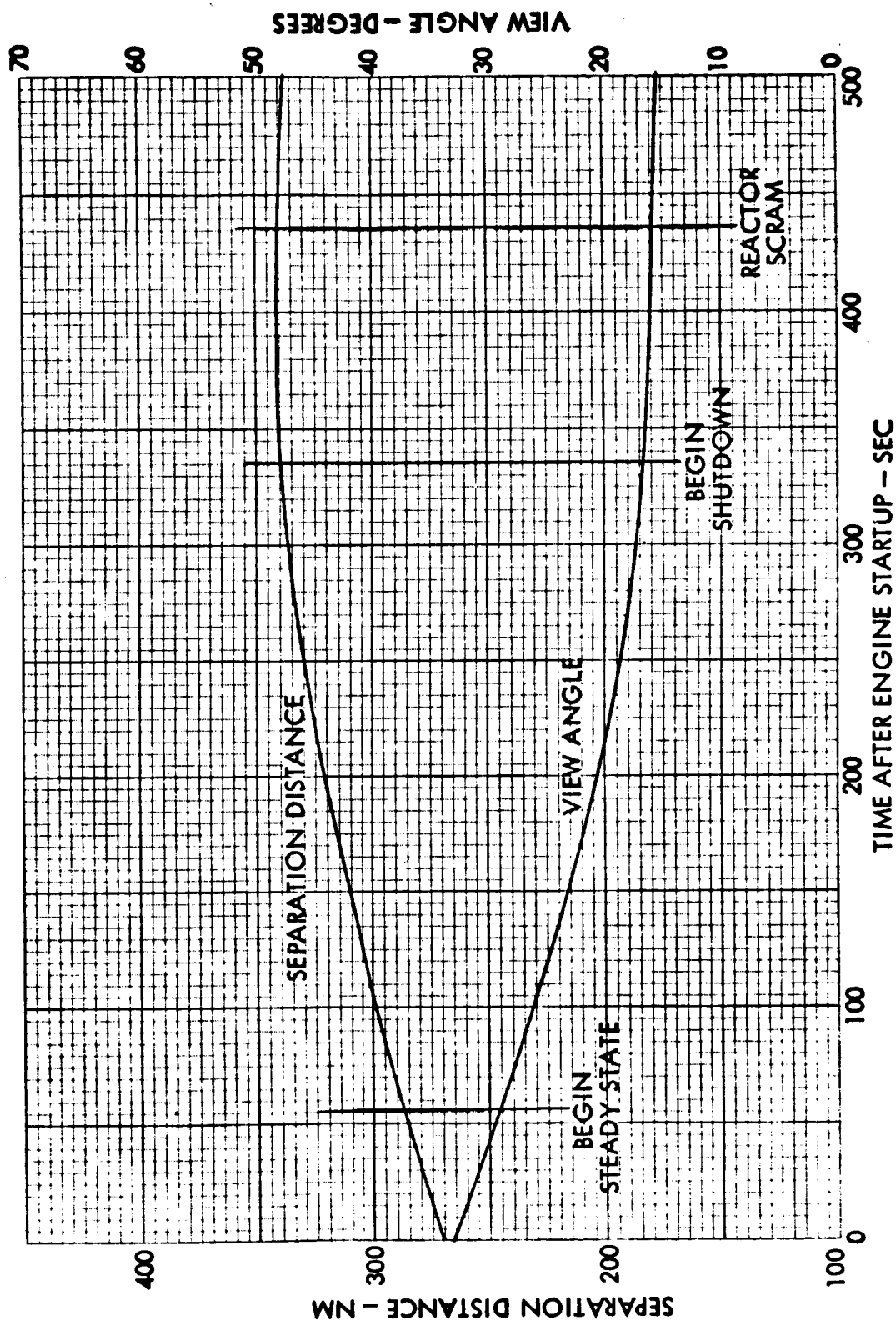


Figure 9 - Separation Distance and View Angle Between
OLS and RNS During LOI Burn

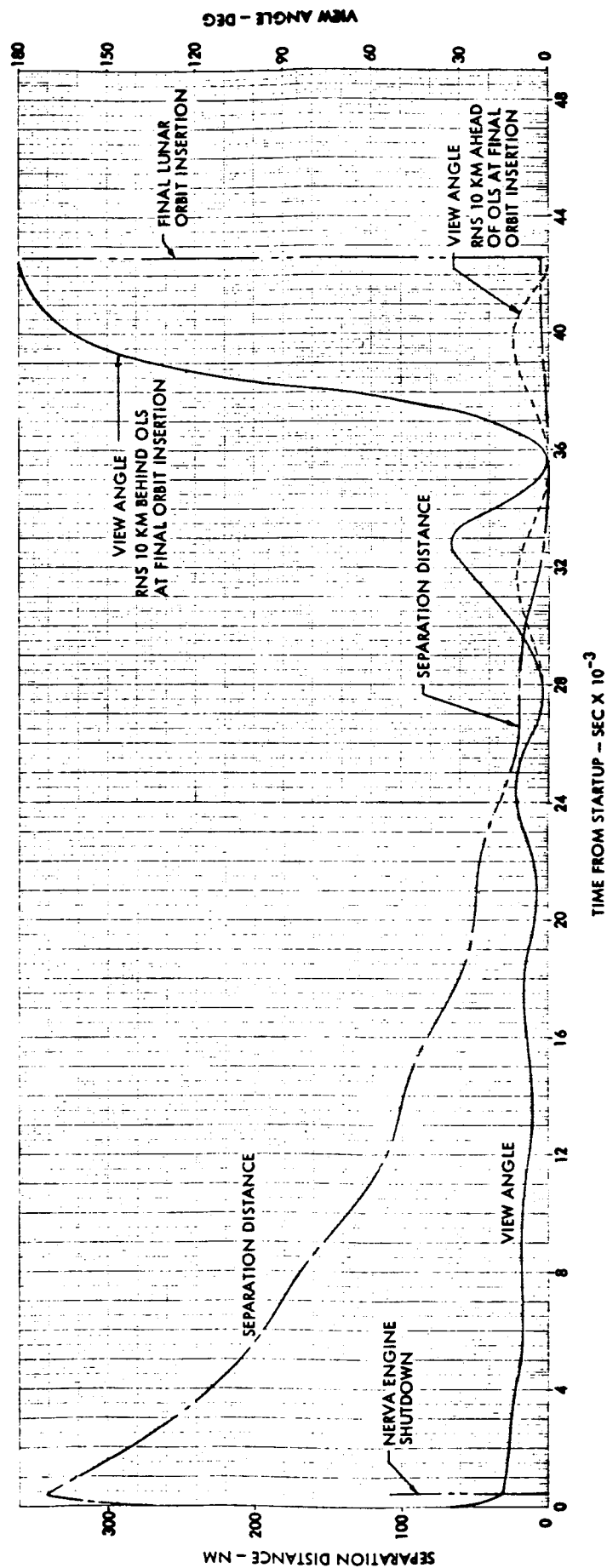


Figure 10 - View Angle and Separation Distance to OLS During Cooldown Phase of N-PTV LOI Maneuver

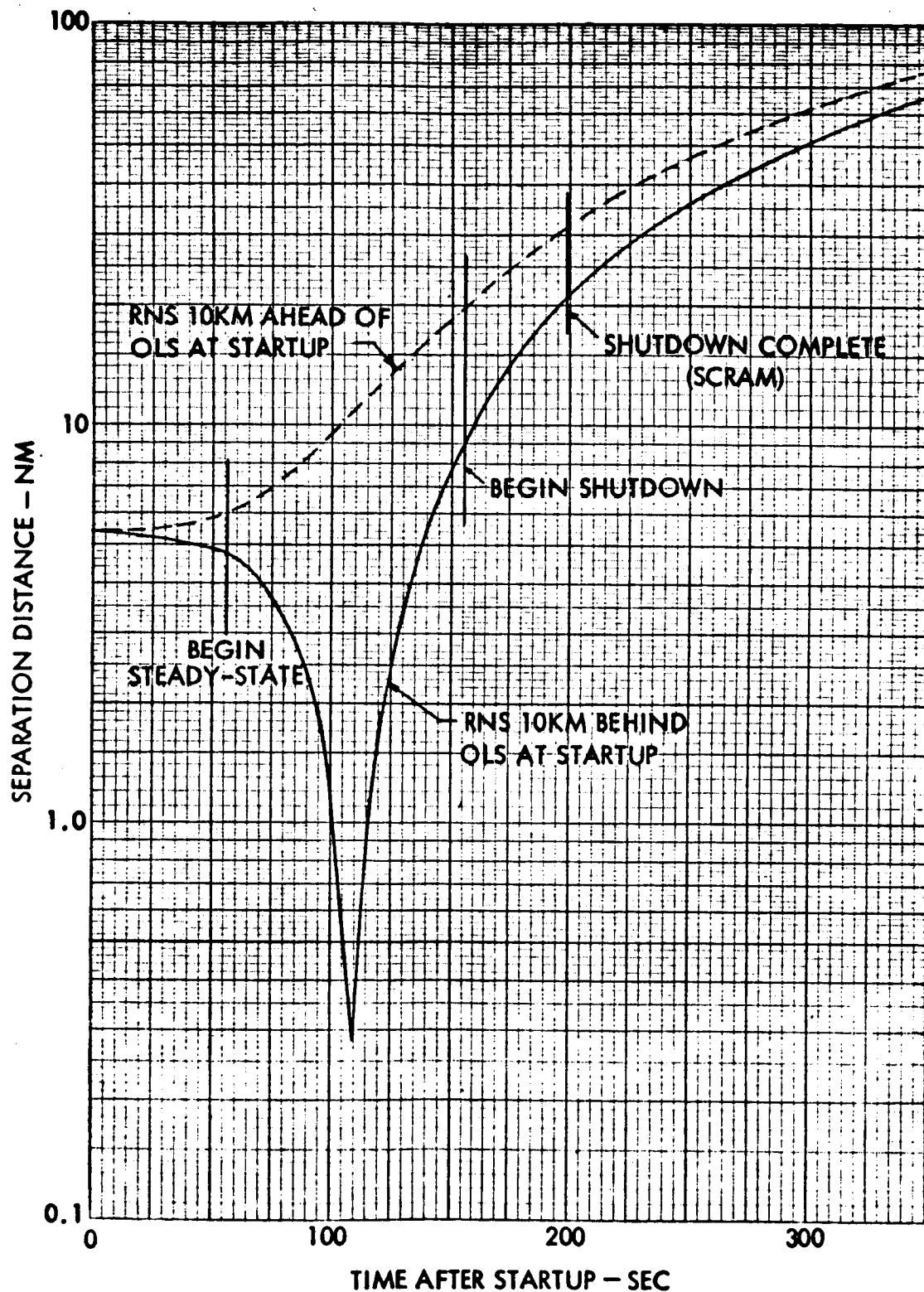


Figure 11 - RMS-OLS Separation Distance During First Burn of Three-Burn Lunar Departure Maneuver

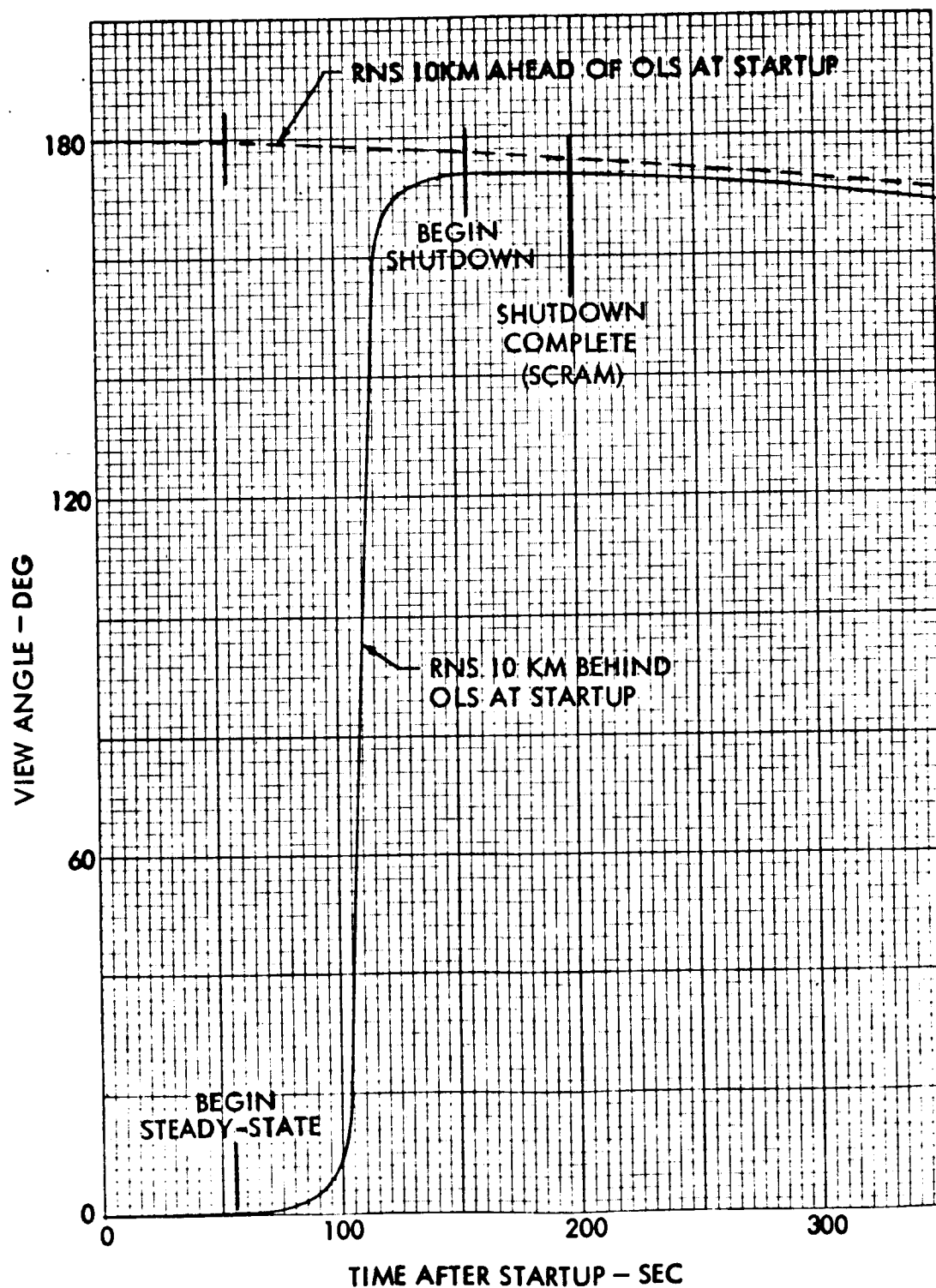


Figure 12 - RNS View Angle from OLS During First Burn
of Three-Burn Lunar Departure Maneuver

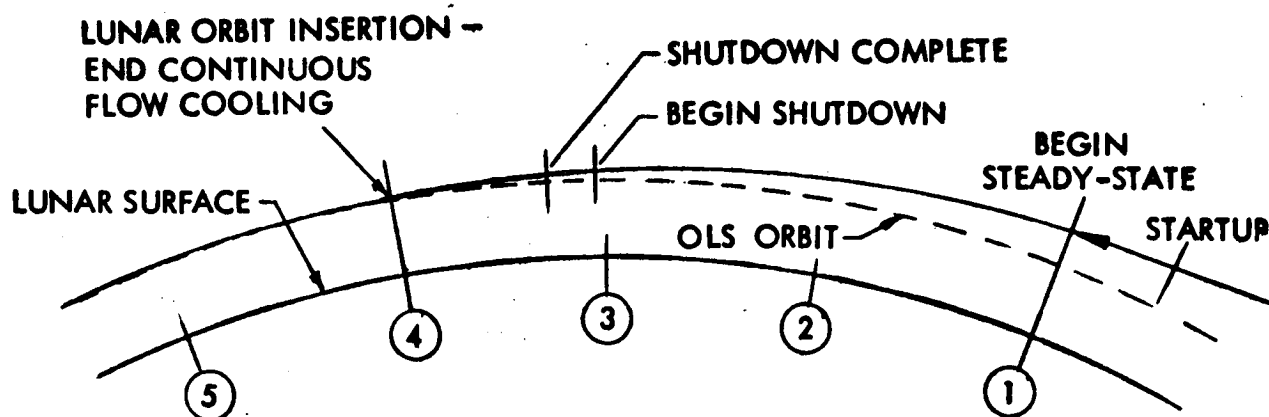


Figure 13 - Relative Location of Lunar Surface Positions With Respect to RMS Incoming Trajectory - Low Altitude Approach

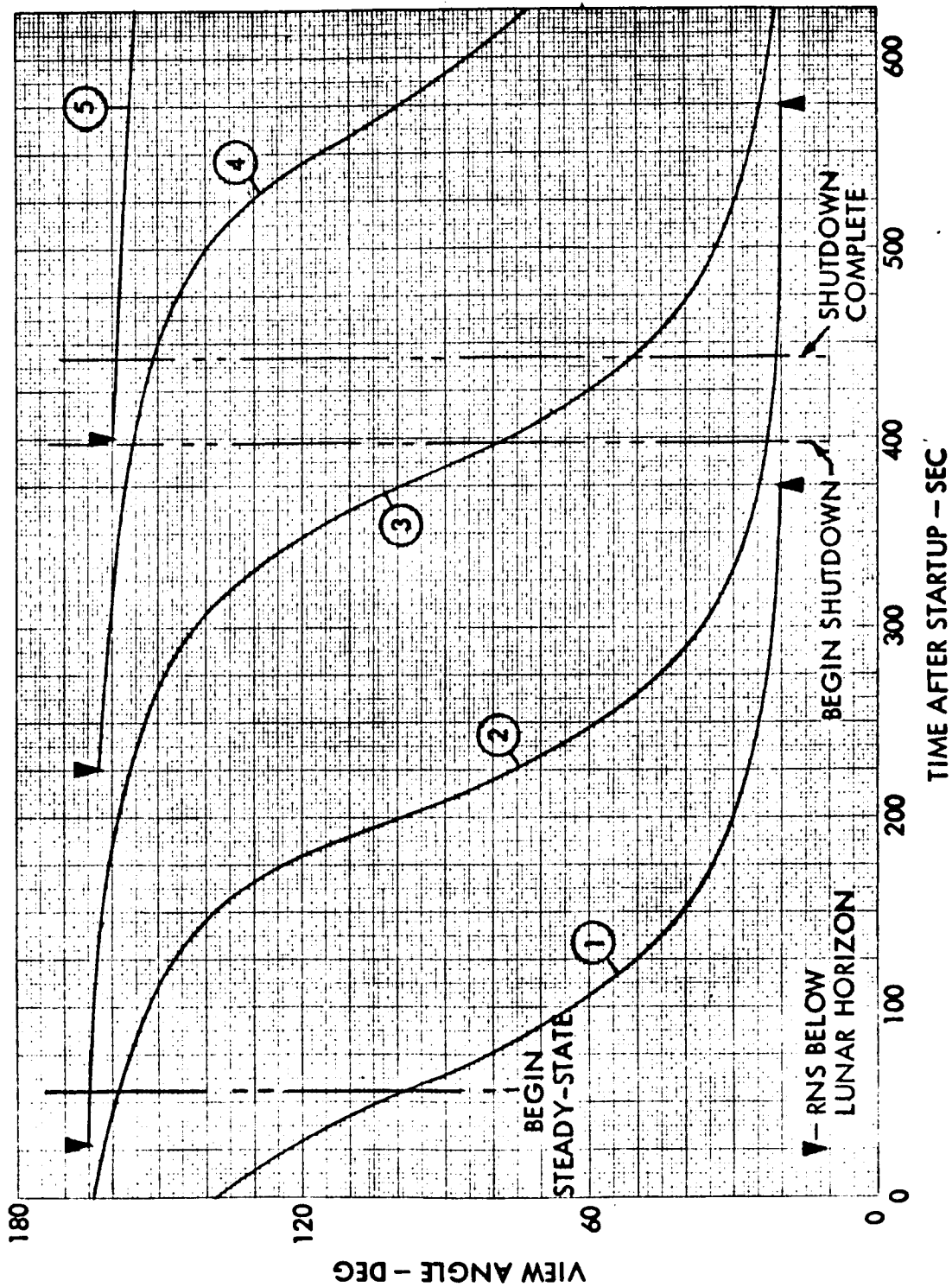


Figure 14 - RNS View Angle From Indicated Surface Positions
During Low Altitude LOI Burn

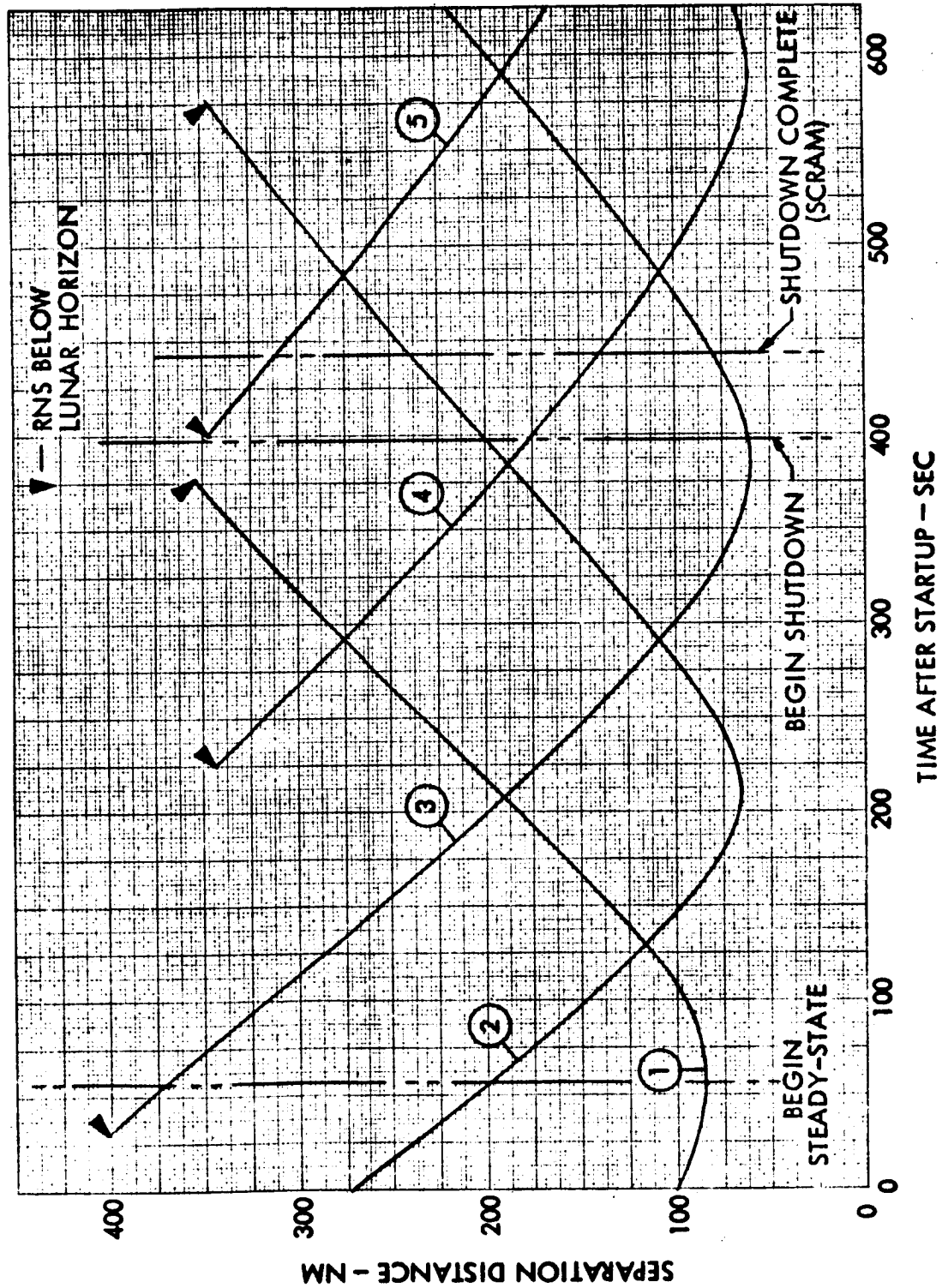


Figure 15 - Line of Sight Distance to RNS From Indicated Surface Positions During Low Altitude LOI Burn

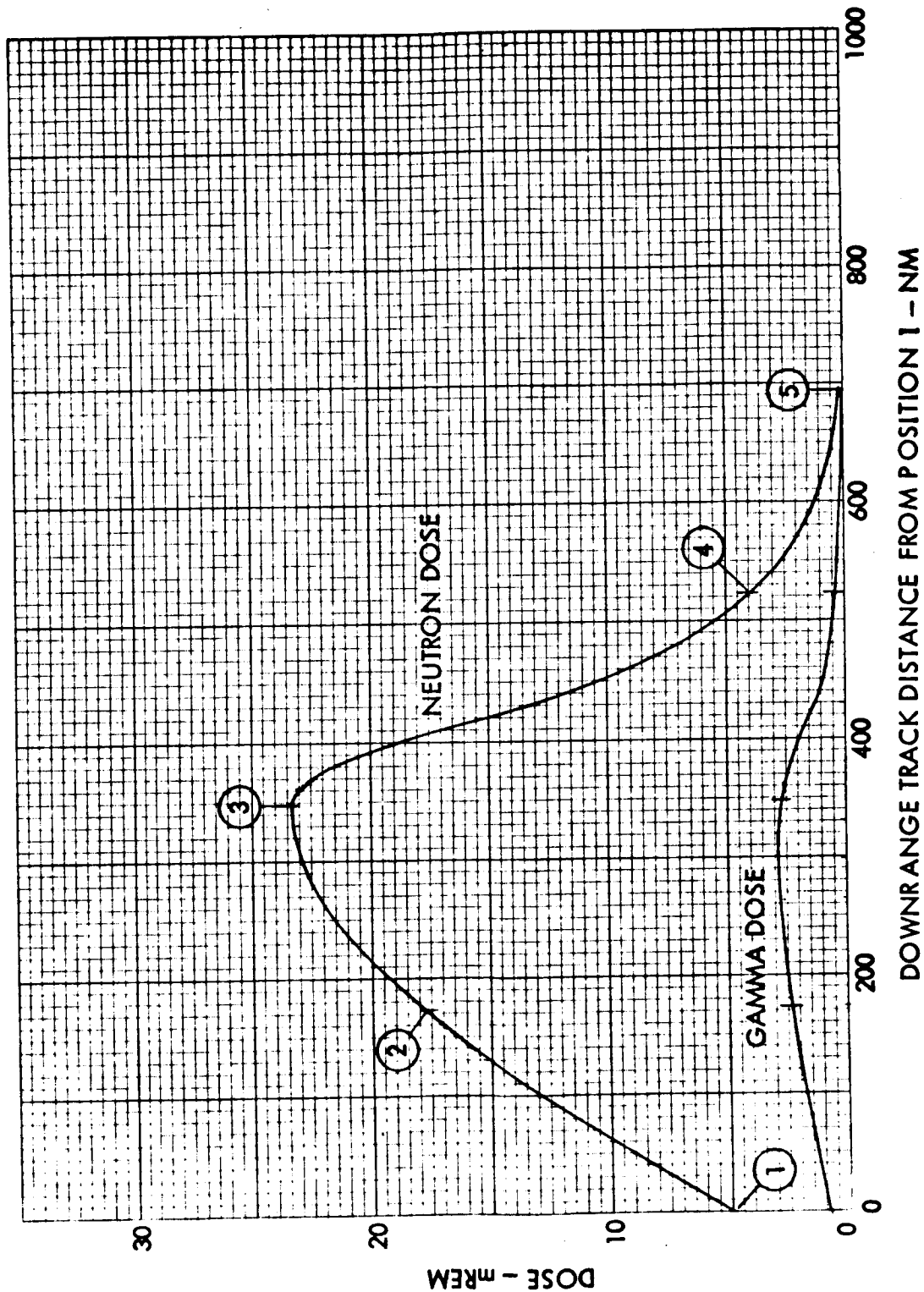


Figure 16 - Neutron and Gamma Dose to Lunar Surface
During Low Altitude LOI Maneuver

SUPPLEMENTAL DATA REPORT NO. 2
SOME PROS AND CONS ON THE "BUDDY SYSTEM" FOR EVA

INTRODUCTION

A central issue regarding EVA operations is the question of the number of EVA astronauts to commit simultaneously to the potentially hostile lunar surface or lunar orbit space environment. The "Buddy System" concept, which had its origins in the military realm, as applied to space activities involves the commitment of at least two astronauts at a time for all activities so that each can look out for and assist the other in the face of some danger which threatens one of the astronauts. The "Buddy System" offers immediate proximity of assistance in case of a variety of problems, both anticipated and unforeseen which may arise. Counter-arguments to the Buddy System include the consideration that the danger or hazard which affects one astronaut, i.e., much like the drowning swimmer dragging down his rescuer. Ensuing paragraphs explore a variety of considerations which affect the advisability of the "Buddy System" during lunar space activities.

DEFINITION OF BUDDY SYSTEM

The buddy system is defined as that operational mode of activity wherein at least two members of a space mission crew perform tasks with both (all) members conducting tasks while near each other at the same site. The buddy system necessarily includes the capability for each crew member to use the subsystems of his fellow crew member by the existence in their equipment of hardware which permits such mutual (multiple) use. It may include 2 tugs, 2 flyers, 2 rovers, separated bases, etc.

Thus, if each of M crew members carries N subsystems (life support, communications, power, etc.), there are then MN subsystems for their support.

The psychological comfort of having a fellow crew member immediately available in the event of accident, equipment malfunction, illness, or any other irregularity serves to greatly increase the confidence of the buddy system crew.

By no stretch of the imagination can the buddy system be considered to be in effect if one member of the team is outside a spacecraft or lunar base while his monitor(s) is inside the spacecraft or base; no matter whether the latter is suited-up or not.

CREW SIZE AND FUNCTION

A basic consideration in establishing the requirement for the "Buddy System" in a given system is the basic crew size and the functions which the crew must perform to maintain a viable habitat. For example, a two-man crew associated with a lunar shelter offers minimal flexibility if one man must continuously monitor habitat life support and other critical systems to cope immediately with a possible equipment system malfunction. In this context, another consideration is the extent to which Earth surveillance of the lunar habitat is provided so that habitat system malfunctions can be reported immediately to the crew during periods when both men are EVA.

As crew size becomes larger, the issue of availability of a second or buddy astronaut assumes less importance. With a three-man lunar habitat crew, one man can remain in the habitat to monitor critical systems while the other two can assist each other during EVA operations. When the crew numbers four or more, a greater degree of flexibility and safety can be achieved by committing two astronauts to the lunar EVA environment, while a third remains in the airlock in a suited pressurized condition ready to assist one or both of the EVA astronauts as required. The fourth man remains behind the monitor vehicle/shelter systems.

CASES WHERE THE BUDDY SYSTEM PRODUCES SAFETY ADVANTAGES

Aside from safety considerations, there are many EVA tasks which can be performed more expeditiously by two men working together as opposed to a solo effort. Safety advantages are envisioned in the following instances:

1. Motion Sickness Effects. Nausea induced by motion effects may occur as a result of lunar vehicle motion over the lunar surface or through uncontrolled spinning or tumbling during lunar orbit EVA operations. In addition, nausea in the space suit may occur as a result of illness. Hazards associated with vomiting in a space suit have been elaborated upon in Hazard Study 35. Due to the generally incapacitated state of the motion-sick astronaut, including possible obscuration of the visor, a "buddy" astronaut is highly desirable in terms of guiding and assisting the disabled astronaut as soon as possible to a safe haven. This is especially important in the case where the astronaut is operating with a cabinless lunar rover some distance from the shelter, and during lunar orbital EVA.
2. Suit/PLSS Damage or Malfunctions. Hazards inherent in EVA operations include suit rupture, portable life support system failures or possible interruption of life support provisions in switching from one back-pack to another during EVA. In each of these cases, depending on the rate of escaping life support gases and depressurization, immediate assistance rendered by a buddy astronaut can make the difference between saving or losing the astronaut whose extravehicular mobility unit (EMU) has been compromised. The "buddy" astronaut, as described more fully in Hazard Study 23, can aid the endangered astronaut by assisting him to hook on to a spare PLSS or vehicle mounted ECS System, share his own PLSS with the astronaut, and/or help guide the astronaut to a safe haven.
3. Dysbarism Effects. Physiological problems may arise when the astronaut transitions from higher pressure, mixed gas lunar base or shelter environments to the 3.5 psi, pure oxygen space suit environment. These symptoms, e.g., the bends, are described in detail in Hazard Study 39. Since it is unlikely that the onset of these disabling symptoms

would strike two EVA astronauts simultaneously, the affected astronaut could be returned to a safe shelter and recompressed at higher pressures with the assistance of a buddy astronaut. For example, an astronaut suffering severe bends symptoms might have serious difficulties in safely guiding a lunar rover back to a lunar shelter on his own.

Operational Accidents. In addition to the above-mentioned categories of established and well-defined potential hazards, there are a variety of unpredictable accidents that may occur in the course of normal EVA operations where a buddy astronaut could provide immediate assistance. Such representative accidents include:

1. Falling into a crater or injury from other lunar surface physical hazards.
2. Lunar vehicle overturn.
3. Falling off platform of lunar roving vehicle.
4. Tripping over emplaced items of scientific equipment.
5. Snagging of hoses connecting suit and PLSS.
6. Injury from manual deployment of lunar hardware; scientific or auxiliary vehicles.
7. Uncontrolled spinning or tumbling during lunar orbit EVA.
8. Minor tear, puncture, or rupture of pressure suit.

In addition to providing assistance subsequent to any of the aforementioned types of accidents, the "buddy" astronaut can serve an important role in the prevention of these accidents. The encumbering space suit restricts the astronaut's senses. Vision is limited, hearing is curtailed and the cutaneous or touch sense is largely voided by the enveloping space suit. For these reasons, two pairs of eyes may well be better than one in anticipating potential dangers. Certainly there are sufficient precedents from diving to mountain climbing to justify the buddy system when operating in hostile environments.

Crew Error. In case of crew error on the part of one crewman the buddy astronaut is present to monitor and prevent or aid in remedying the error.

CASES WHERE THE BUDDY SYSTEM MAY JEOPARDIZE BOTH ASTRONAUTS

As we mentioned earlier, an argument against the "Buddy System" is that a hazard or danger which threatens one astronaut, could envelope both astronauts. With a small crew, this could jeopardize not only the crew, but the entire mission. Environmental hazards that might simultaneously affect both EVA astronauts include:

1. Meteorite showers.
2. Periods of solar radiation intensity.
3. Moon quakes.

In addition to these environmental hazards we must also consider the case where in attempting to rescue a disabled astronaut, the assisting astronaut is ensnared in the same dangerous situation, thereby compounding the seriousness of the situation, e.g., an astronaut who is injured attempting to retrieve his companion from a crater floor.

CONCLUSIONS

The safety advantages inherent in the "Buddy System" mode of operation generally outweigh the probability that both EVA astronauts will be enveloped in a common catastrophe. This generalization definitely applies where the available crew complement numbers three or more.

Where only two crew members are available to man a lunar habitat, it becomes imperative to weigh the system monitoring requirements for preserving a safe habitat against the safety and operational benefits accruing from simultaneous EVA activities, leaving the shelter unattended. The shelter, under these circumstances, can be left unattended only where remote surveillance of critical systems is available to alert the astronauts to return to the shelter and attend to malfunctions in a timely fashion.

When solo astronaut EVA operations are indicated because of 'overriding' concern for habitat system monitoring, the astronaut who remains in the shelter should be suited/pressurized and on standby to aid the EVA astronaut, as required, in an emergency. Provisions should be made for visually monitoring the EVA astronaut's activities, and the shelter and EVA astronauts should be in constant communications contact. EVA excursions from the shelter under these circumstances should be limited.

SUPPLEMENTAL DATA REPORT NO. 3
SUGGESTIONS TO IMPROVE SAFETY AT A LUNAR SURFACE BASE

INTRODUCTION

This supplemental study presents some ideas for improving personnel safety at a lunar surface base through attention to basic site layout, deployment, crew ingress/egress, and deployment of scientific equipment.

LUNAR SURFACE BASE SITE LAYOUT

There are many ways in which to arrange a lunar surface base to enhance the safety of the crew, and many trade-off studies can be performed to ensure maximum protection for the crew. Four major approaches are shown on Figure 1, along with a summary description of the major advantages and disadvantages of each site layout.

Of particular importance is the distance between the lunar base itself and the tug landing sites, the major hazard being damage to the personnel shelter through bombardment by secondary ejecta thrown up by the tug's engine plume during final approach, touchdown and take-off. Reference 1 recommends a minimum distance of one mile, based on ejecta damage requirements, and a maximum distance of $1\frac{1}{4}$ miles based on crew walking capability.

There are a variety of ways to reduce this plume impingement problem by preparing the landing site to be used by the tugs. The initial landings, of course, will not have this luxury unless the sites are prepared remotely, a not very likely possibility. Figure 2 summarizes some approaches that could be used to protect the base.

The problem of having the tug landing site about a mile from the base introduces hazards also. If there will be tug landings and take-offs at the rate of one every two months and entire crews are to be exchanged every four months,

there will be much ingressing and egressing and donning and doffing of space suits and back-packs and getting up and down the sides of the base and tugs (the equivalent of a nine-story building). If the crews do not walk, they will have to be clambering on and off slow moving and complicated roving vehicles, all of which introduce hazards of their own; in other words, it will be a constant battle with the dusty lunar surface and the ingenious equipment designed to travel on that surface. It is, therefore, suggested that to reduce the hazards of the lunar surface base consideration should be given to the elevated crew and cargo transfer system shown on Figure 3 whereby, after initial set-up, the astronaut need never touch the lunar surface for routine cargo handling purposes and crew exchanges.

DEPLOYMENT OF LUNAR SURFACE BASE

The major activities for setting up the base, once the site has been prepared, are unloading the cargo from the tugs, transporting cargo from tug landing site to base site, and possibly some degree of lunar soil handling. Figures 4 through 7 list some of the most likely methods and equipment to be used, crew activities associated with those methods, and some of the safety problems and requirements which will emanate from that activity.

CREW INGRESS/EGRESS

The major problems associated with ingress and egress are dysbarism (see Hazard Study 39, airlock operation reliability, extravehicular mobility unit reliability, and contamination. The lunar surface base atmosphere is most likely to be a two-gas (O_2+N_2) atmosphere, whereas the pressure suit the astronaut wears is probably going to be 100% oxygen as in the Apollo program. The effects (e.g., denitrogenization) of switching from a high pressure two-gas atmosphere to a low pressure, 100% oxygen, suit atmosphere and vice-versa are the subject of continuing study by the various environment control and life support system experts working on the space station and lunar base studies, and are too complicated for thorough research in this study. The major difficulties will not be the nominal operation of the

airlock/shelter/suit interface but rather the emergency conditions requiring fast reaction by the crew. One suggestion is offered here which may be pertinent is that, during a tug rescue mission from the orbiting lunar station to the surface, the time between separation from the station and touchdown on the surface could be used to change the tug atmosphere from two-gas to 100% oxygen so that when the rescued crewmen are brought on board they will not have denitrogenization problems, and during the return flight the change could be reversed.

The physical business of getting into and out of the base to the lunar surface has some hazards which are summarized on Fig. 8. A basic requirement is to be sure the stairs, elevator, or whatever means is chosen for getting up and down is at least big enough to accommodate one prone stretcher case plus a suited astronaut; all doors, hatches and airlocks should also be designed with the stretcher case in mind; the height of the door sill from the lunar surface should be kept to a minimum.

It is suggested that the base/cabin rover interface be designed such that the driving crew can make a shirtsleeve ingress/egress between the two structures. The idea is illustrated in Fig. 9. Such a scheme would save valuable time during a rescue mission by the cabin rover.

DEPLOYMENT AND OPERATION OF SCIENTIFIC EQUIPMENT

The hazards involved with deployment of scientific equipment are basically those associated with EVA activity while setting up, erecting and operating such large and diverse structures as a 300 meter drill and the enormous telescope complex which extends 5.6 miles across and is 10 miles away from the main base as shown in Reference 2. Unless some form of automation for deploying such items is worked out, very long periods of EVA and driving, with their associated hazards, will be necessary. Wherever possible all equipment operations should be automated. For some of the equipment a

remote temporary shelter could be used to shorten driving time and double as an emergency safe haven; something like the Goodyear self-erecting shelter (Ref. 3) could be put to good use here since it is lightweight and transportable.

REFERENCE AND DATA SOURCES

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2. PD 70-40 Lunar Base Synthesis Study, First Interim Progress Report, North American Rockwell, October 1970
3. GET-12246 - Lunar Staytime Extension Module - Goodyear Aerospace Co.
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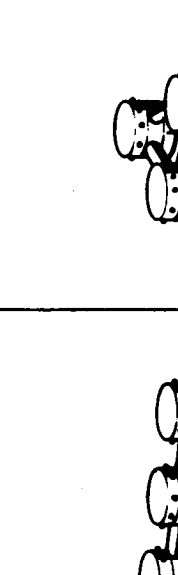
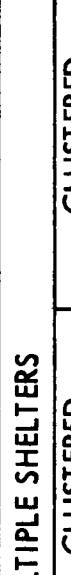


	MULTIPLE SHELTERS			
	SINGLE SHELTER	DISPERSED AS LANDED	CLUSTERED IN-LINE	CLUSTERED CIRCLE
EXPLOSION	<p>A</p>  <p>COULD BE CATASTROPHIC TO ENTIRE CREW & BASE</p>	<p>B</p>  <p>COULD BE CATASTROPHIC TO ONE SHELTER ONLY</p>	<p>C</p>  <p>COULD BE CATASTROPHIC TO ALL BUT LESS LIKELY</p>	<p>D</p>  <p>SAME AS C BUT SOMEWHAT MORE HAZARDOUS</p>
FIRE	<p>DITTO - HOWEVER ENTIRE CREW AVAILABLE TO TAKE ACTION</p>	<p>DITTO - BUT CREWS UNABLE TO PROVIDE FAST RESPONSE</p>	<p>DITTO - HOWEVER ENTIRE CREW COULD HELP. BULKHEADS TO PREVENT SPREAD.</p>	<p>DITTO</p>
CONTAMINATION	<p>LARGE QUANTITIES OF CONTAMINANTS NECESSARY TO SPOIL ATMOSPHERE & EASIER TO DETECT</p>	<p>FASTER PROBLEM THAN IN A BUT CREW COULD USE OTHER SHELTERS</p>	<p>SAME AS B BUT CREW CAN TRANSFER FASTER TO AID IN ISOLATING PROBLEM SHELTER</p>	<p>CONTAMINATION BETWEEN SHELTERS MORE DIFFICULT TO ISOLATE</p>

Fig. 1 LSB - Site Layout Safety Effects


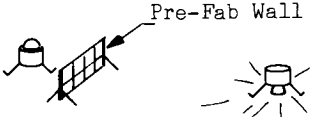
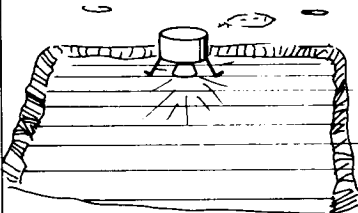
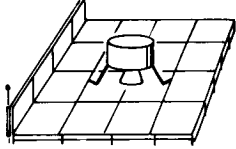
LUNAR SURFACE BASE - HAZARDS ANALYSIS - DEPLOYMENT OPERATIONS			
CONCEPT	SPECIAL EQUIPMENT	CREW ACTIVITY	SAFETY ASPECTS
1) No special preparation Locate landing sites widespread from each other o Locate base in natural crater	None	None	Transportation to and from base to tug sites; tug maintenance may require temporary shelter at tug site for work crews
2) <u>Blast Walls</u> 	Bulldozer; Lifter; Carrier	Extensive Driving	Wall probably not very high requiring fair separation distance; Same as 1)
 Pre-Fab Wall	Lifter; Assembly Tools; Foundation Pads	Extensive EVA for offloading and assembly	Wall could be high and close to base, or low and away from base; very reliable foundation required
3) <u>Prepared Surface</u> 	Bulldozer; Scraper/ Leveller; Soil Carrier; Chemical Solidifier?	Extensive Driving	Testing of effectiveness of actual site required before commitment of LSB; probable that loose material can be ejected
4) <u>Rigid Landing Pads</u> 	Bulldozer; Scraper/ Leveller; Soil Carrier? Assembly Tools; Tie-Downs; Foundations; Trailer for transporting panels	Extensive Driving and EVA	Provides excellent control of the engine plume once the set-up problems have been overcome
SAFE DESIGN CONSIDERATIONS <ul style="list-style-type: none"> o Landing gear spread o Landing loads, velocities o Proximity of beacon o No. of landings o Angle of repose of soil o Soil properties o Engine exhaust velocity o Ht. above ground at engine cut-off o Reusability o Damage to tug nozzle & heat shroud o Type of soil at sites o One big site vs several sites 			

Fig. 2 Site Preparation

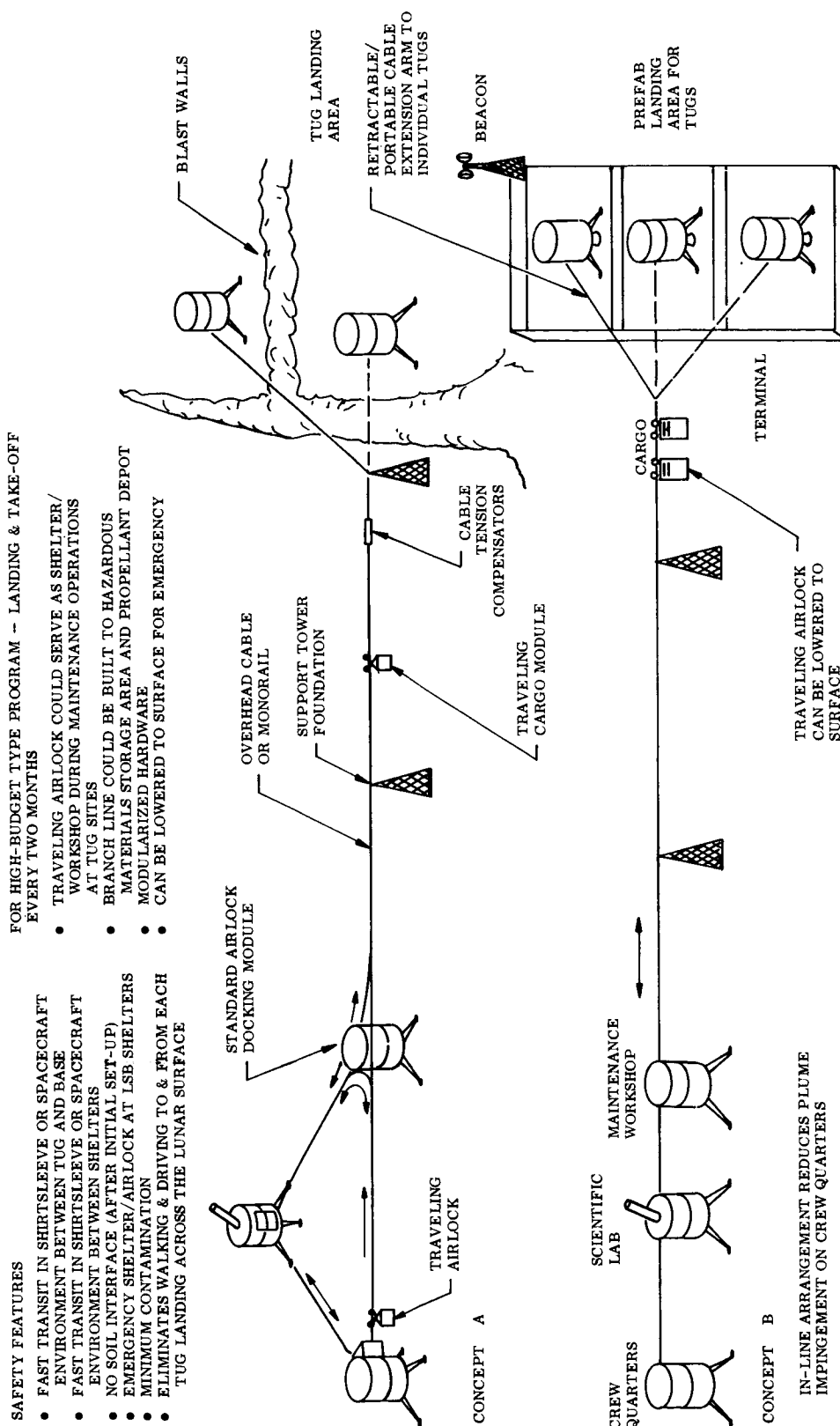


Fig. 3 Typical Lunar Base Complex Elevated Crew and Cargo Transfer System

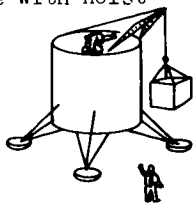
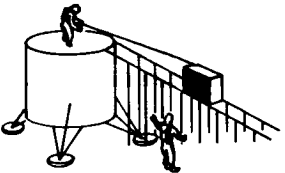
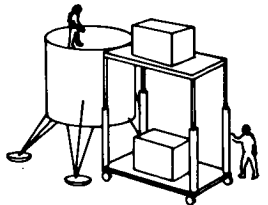
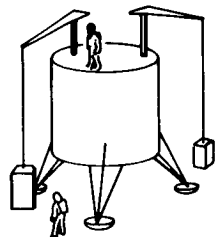
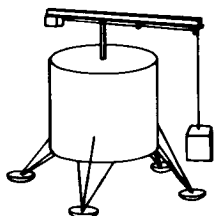
LUNAR SURFACE BASE - HAZARDS ANALYSIS - DEPLOYMENT OPERATIONS		
CONCEPT	CREW ACTIVITY	SAFETY ASPECTS
1) A Frame With Hoist 	EVA on top deck & surface; Controlled by both crewmen; intercom	Handling cables may be required to prevent swinging; handrails required on deck; emergency equipment required on top deck and at surface
2) Ramp 	EVA on deck and surface; Extensive EVA for assembly	Should payload get stuck on ramp - EVA activity may be required on rails, dangerous; Provide walkway and handholds along rails and deck
3) Hoist Platform 	Same as 2)	Same as 2); Probably require much EVA for maintenance; Ladders required
4) Davits 	EVA on deck and surface	Extensive intercom between deck and surface crews; may require cables to prevent swaying of payloads into vehicle and crew
5) Monorail & Hoist 	Same as 4)	Same as 4)
SAFE DESIGN CONSIDERATIONS: <ul style="list-style-type: none"> o Perform jobs remotely where possible o Use buddy system (on deck & surface) o Multiple intercom capability o Reduce handling time to minimum o Provide crew danger warnings o Simulated training devices 		

Fig. 4 Unloading

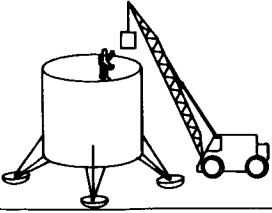
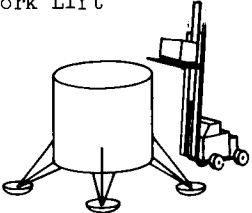
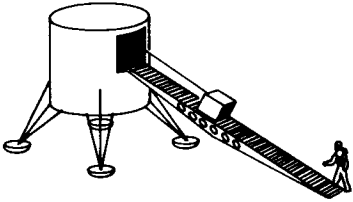
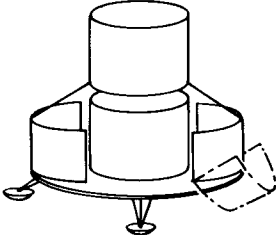
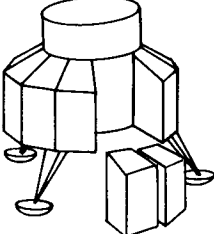
LUNAR SURFACE BASE - HAZARDS ANALYSIS - DEPLOYMENT OPERATIONS		
CONCEPT	CREW ACTIVITY	SAFETY ASPECTS
6) Mobile Crane 	Extensive EVA; Driving	Precision control required; Minimum of 3 crewmen with much intercom required; Possible damage to vehicles and crew
7) Fork Lift 	Same as 6)	Same as 6)
8) Roller Conveyor 	EVA for set up; control	EVA required for maintenance and trouble-shooting
9) Saddle Bag - Hinged 	EVA for unloading modules?	Could be unloaded to surface or transporter remotely
10) Hinged Modules 	Same as 9)	Same as 9)
FOR ADDITIONAL UNLOADING CONCEPTS SEE DEPLOYMENT PROCEDURES, LUNAR EXPLORATION SYSTEMS FOR APOLLO, LOCKHEED REPORT NO. LMSC-665606, VOL. III APPENDIX PAGE 57		

Fig. 5 Unloading

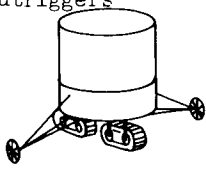
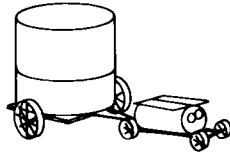
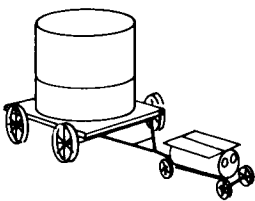
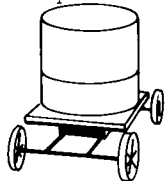
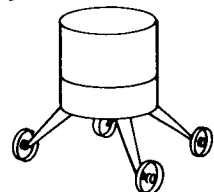
LUNAR SURFACE BASE - HAZARDS ANALYSIS - DEPLOYMENT PROCEDURES		
CONCEPT	CREW ACTIVITY	SAFETY ASPECTS
1) Bicycle Transporter With Outriggers 	EVA for installation of tracks, wheels, etc; EVA for control; Road Building	Unless provided with good road, especially for outriggers the whole assembly would get stuck, damaged or tip over
2) Two Wheels Plus Large Rover 	EVA for disassy. of landing gear; assy of wheels; driving/towing	Requires very good road; shelter/cargo will want to pitch forward and backward which may overload Rover; requires observers outside of Rover
3) Four Wheel Trailer Plus Large Rover 	Similar to 2)	Good road required though not as critical as 2); requires observers outside of Rover
4) Four Wheel Trailer Self Propelled 	EVA for disassy of landing gear; assy of wheels; and for controlling steering	Same as 3)
5) Wheels attached to Landing Gear - Self Propelled 	EVA for wheel attachment and control steering	Same as 3)
SAFETY CONSIDERATIONS: o All concepts require extensive EVA for assembly unless the wheels, trailers, controls, etc. can be built-in and then remotely hinged or folded out after landing. o Control & steering could be remote?		

Fig. 6 Transportation of LSB and Cargo Modules

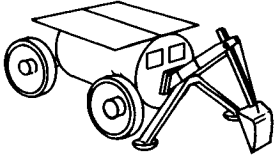


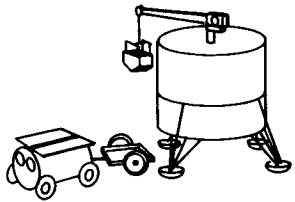

LUNAR SURFACE BASE - HAZARDS ANALYSIS - DEPLOYMENT PROCEDURES		
CONCEPT	CREW ACTIVITY	SAFETY ASPECTS
1) Backhoe 	Driving; EVA for installation of special purpose attachments	Special dust & falling rocks protection required (at windows especially); good visibility required under all operating conditions; maybe design attachments so they can be installed without EVA
2) Dragline 	EVA for set-up	Possibly good for remote Ops; some difficult EVA maintenance chores; infallible foundations required
3) Soil Thrower 	Driving (towing); EVA for set-up alignment	Doubtful if soil can be accurately thrown; control problems; poor visibility
4) Soil-Box/Trailer/Rover 	Driving; Attachment hook up; Controls EVA for set-up	Will require sophisticated controls to get accurate function; avoid backing-up type situations.
5) Bucket Conveyor 	Driving (towing); set-up EVA for repositioning	Probably much EVA for maintenance; will be difficult & dangerous to inspect during operation
SAFE DESIGN CONSIDERATIONS <ul style="list-style-type: none"> o Use automation & remote control, checkout, assembly, etc., wherever possible o Design must consider soil effects on machinery & materials o Protection req'd around all moving parts o Minimum maintenance o Maximum accessibility o Extensive training programs 		

Fig. 7 - Soil Operations

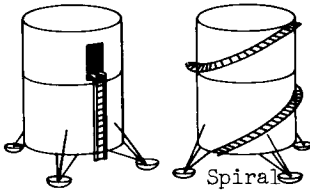
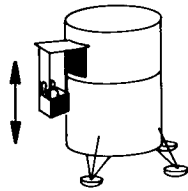
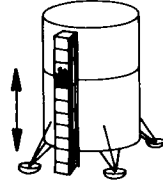
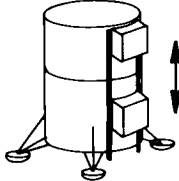
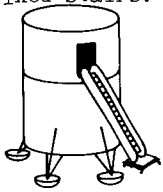
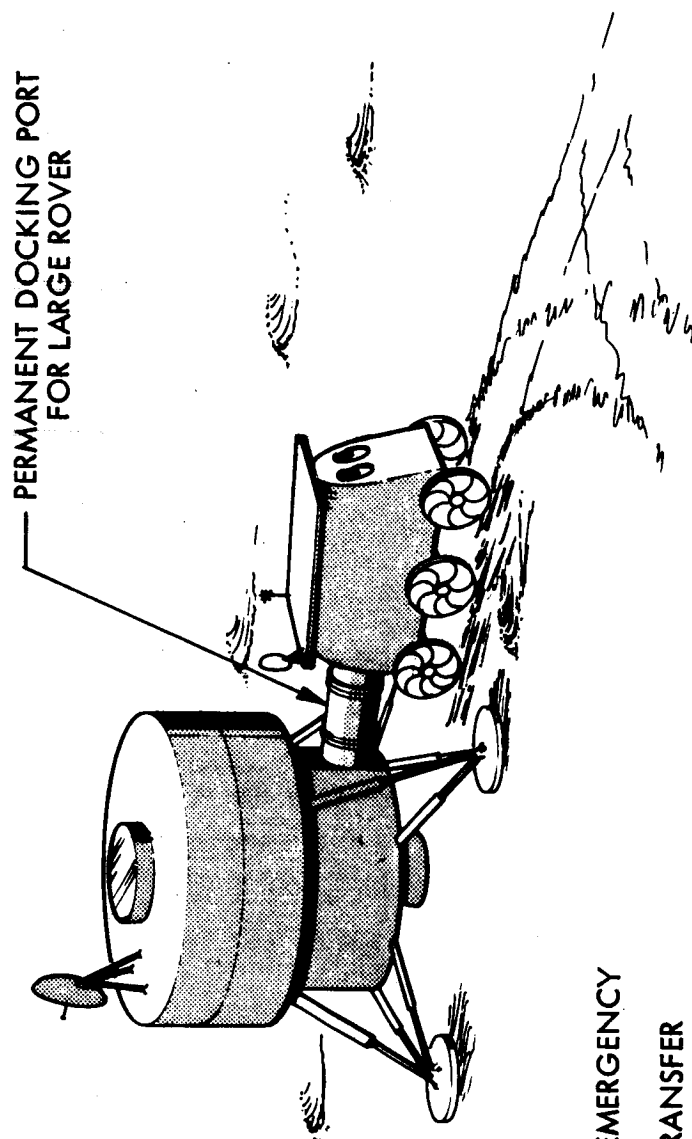
LUNAR SURFACE BASE - HAZARDS ANALYSIS - DEPLOYMENT PROCEDURES		
CONCEPT	CREW ACTIVITY	SAFETY ASPECTS
<p>1) Ladders</p>  <p>Spiral</p>	Climbing/ Walking	Requires both hands and both feet; backwards descent; difficult for injured crewman and extremely difficult for stretcher case; equipment transfer slow; possible to fall or become entrapped; requires extensive hand-rails, platforms, etc.
<p>2) Hoist Platform</p> 	Hoist Control; Standing	Possible temporary isolation of crewmen; will require back-up system of ladder or hoist; possible swaying; should be big enough to take stretcher case plus one other crewman
<p>3) Rigid Elevator Platform</p> 	Hoist control; Standing; Assembly EVA	Possible temporary isolation of crewmen; if mechanical failure occurs structure can be used as ladder/platform; should be big enough for stretcher case & 1 crewman
<p>4) Travelling Airlock</p> 	Airlock control; Standing; Rail assembly EVA?	Requires back-up system; should be big enough for stretcher case, etc.
<p>5) Moving Stairs, or Large Fixed Stairs.</p> 	EVA for assembly; Standing	Requires handholds/platform; May have some problems for injured crewmen/Stretcher boarding problems?; Probably require a fair amount of EVA for maintenance; protection required for all moving parts
<p>Safety Considerations:</p> <ul style="list-style-type: none"> o Door sill should be as close to ground as possible. o Intercomm required during all operations (to surface & shelter) 		

Fig. 8 - Ingress/Egress Operations



- FAST REACTION IN EMERGENCY
- SHIRTSLEEVE CREW TRANSFER
- AVOIDS AIRLOCK HAZARDS
- PROVIDES ALTERNATE EMERGENCY SHELTER

Fig. 9 Rover/Base Shirtsleeve Transfer Scheme

SUPPLEMENTAL DATA REPORT NO. 4

CREW MODULE MINIMUM VELOCITY REQUIRED WHEN LEAVING A ROTATING NUCLEAR PRIME TRANSPORT VEHICLE (PTV)

For the case of a crew module effecting an emergency departure from a rotating* nuclear PTV, the question arises as to the minimum separation rate needed to minimize crew radiation exposure from the NERVA engine. The initial assumption is made that the crew module is provided with a pyrotechnic separation device which permits a rapid, clean separation response. The separation rate is then a function of the tumbling rate of the PTV and the crew module/PTV-c.g. moment arm.

As a first approximation, the crew exposure calculations were computed for a crew module leaving a rotating nuclear PTV with only the relative velocity imparted by the rotating vehicle. For comparison sake, two PTV angular rates were postulated; $1^\circ/\text{sec}$ and $6^\circ/\text{sec}$. For the initial calculations, it was convenient to use NERVA engine radiation data for an engine which had been shutdown for one hour. Other radiation levels could then be considered by extrapolation from related data source graphs.

Figures 1 and 2 present the radiation exposure pulses to the crew module as it leaves the vicinity of the rotating nuclear PTV with only the initial relative velocity imparted by the angular rate. The vehicle configuration data and mass properties data were adapted from Ref. 1.

For the first eleven exposure pulses the integrated radiation dose to the crew is given as follows:

<u>Engine Shutdown Time</u>	<u>Tumble Rate</u>	<u>Crew Exposure</u>
1 hr	$1^\circ/\text{sec}$	42 REM
1 hr	$6^\circ/\text{sec}$	7 REM
0.5 hr	$1^\circ/\text{sec}$	253 REM
0.5 hr	$6^\circ/\text{sec}$	44 REM

*The rotation assumed here is rotation about an axis perpendicular to the longitudinal axis of the PTV

The radiation source data employed in the calculations are presented in Supplemental Data Report No. 1, Appendix E, of this report.

The calculations illustrate that escape from a $1^\circ/\text{sec}$ rotating nuclear PTV presents a requirement for crew module propulsion capability. For the $1^\circ/\text{sec}$ case the crew module leaves the PTV with a relative velocity of 1.18 ft/sec. In order to reduce crew exposure to acceptable limits it would be desirable to have a crew module ΔV capability of approximately 100 ft/sec and a thrust-to-weight ratio of 0.1 or higher. A ΔV capability of this magnitude would permit crew module escape at any time after nuclear engine shutdown with low crew exposure values.

DATA SOURCE REFERENCES

1. Nuclear Shuttle System Definition Study - Phase III, Monthly Progress Report, LMSC/A980259, November 15, 1970.

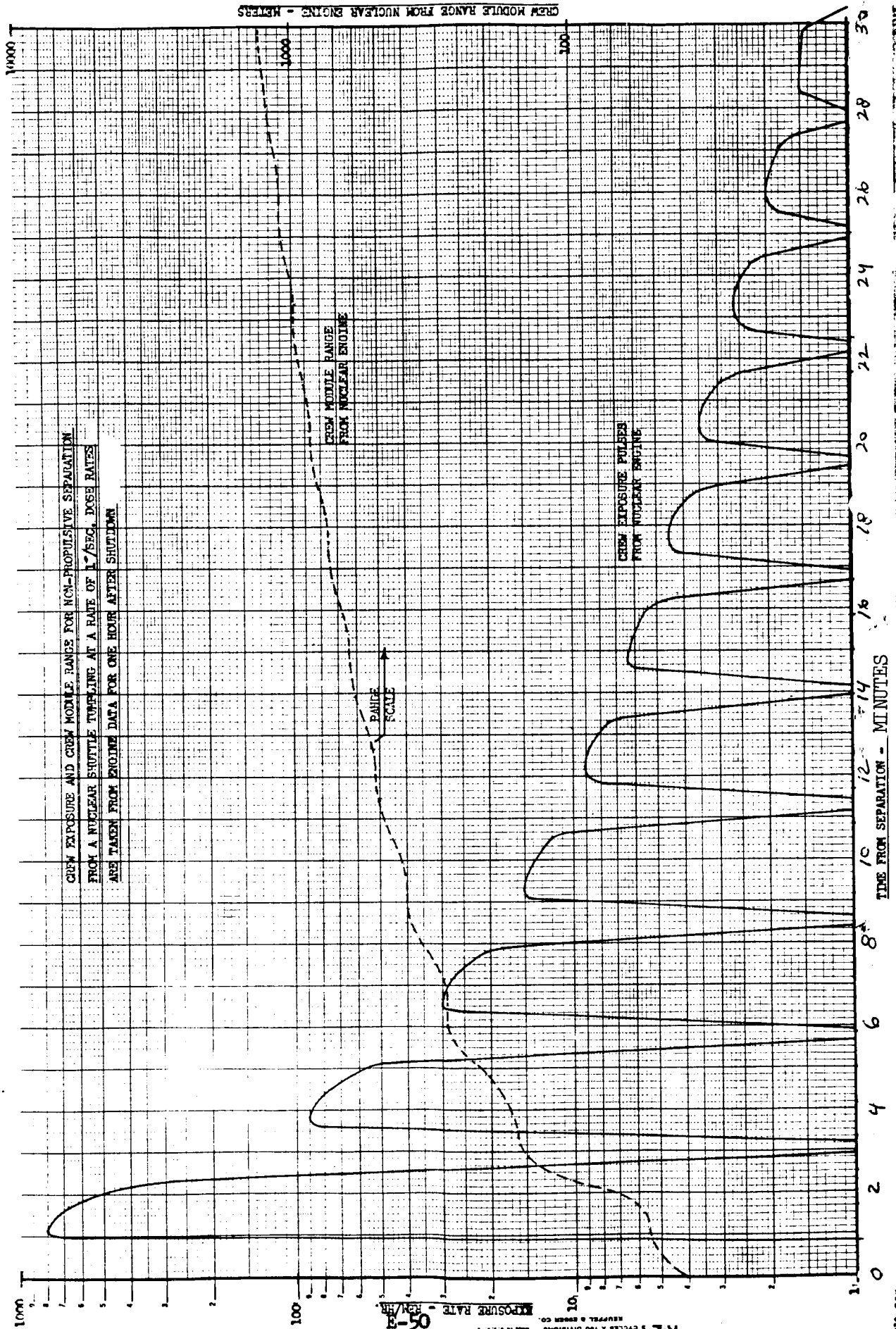


Figure 1

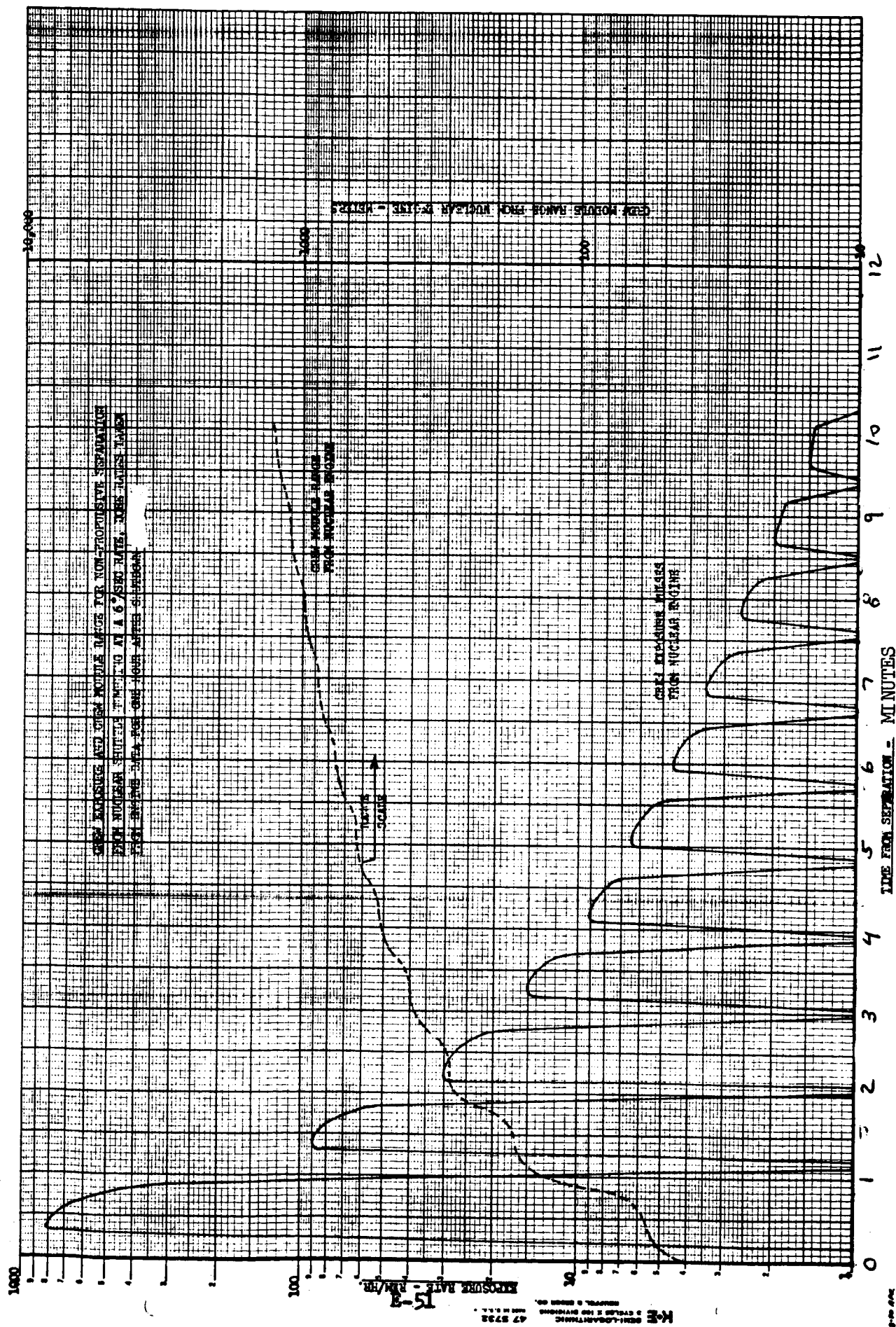


Figure 2

SUPPLEMENTAL DATA REPORT NO. 5

POTENTIAL HAZARDS FACED BY THE APOLLO 14 LUNAR SURFACE ASTRONAUTS

Very good indications of the difficulties that could be encountered by astronauts on future lunar missions requiring navigation procedures and the setting up of experimental equipment were found in the transcript of communications for the Apollo 14 mission.

In Hazard Study 26, Lunar Surface Lighting during Rover Traverses, the effects of travel over the lunar surface during periods of high sunlight angles are discussed. Some of the highlights of that study point to the problems that are faced by astronauts in a rover under the conditions of high sun angles which wash out surface detail to a very large degree. Navigation using surface features under such conditions becomes a difficult - if not impossible - task. Surface glare creates the impression that over wide areas in view there are no depressions or small craters, just a flat featureless plain. Such an impression would raise havoc with attempts at navigation. While it is undoubtedly true that the rover crew would be able to drive out of many craters that they unknowingly drove into, there are altogether too many possibilities that could lead to problems. Much of this navigation problem would be faced by EVA astronauts. The EVA astronauts would see craters and other obstacles as they got close, and so would avoid most, if not all of them. However, after traversing some thousands of feet on foot, it becomes difficult to know just where one is located or, indeed, where particular objects are - like the Cone Crater, for example. Thus, in the Apollo 14 transcript, at about 132.5 hours into the mission, the astronauts state their uncertainty of the way to Cone Crater. At about 133 hours into the mission they note that "the sun angle is....very deceiving".

Earlier in the transcript they claim difficulty in reading flags or scales on the PLSS in the bright sunlight. These are, of course, important parameters and should be readable all the time, independent of lighting, location, etc. The lighting conditions contributed to entanglement in various cables (Ref. Hazard Study 20). Thus at one point one of the Apollo 14 astronauts is entangled in the TV camera cable - for the second time. Later, such entanglement with the same TV cable is noted as occurring a third time. Elsewhere an astronaut notes that some cable he is reeling in has become "....a mass of spaghetti...." - again, a potential problem of entanglement.

In reference to Hazard Study 23 (Hazardous Operations with EMU-EMU Malfunctions) where several suit design improvements were suggested so as to avoid the hazards of loosely hanging hoses, there are incidents shown in the transcript to support the design changes discussed. During the Apollo 14 mission an astronaut's PLSS hose became kinked and resulted in delay of EVA. At one time an astronaut's PLSS hung up on the LM hatch handle. Later the LMP discovered he had inadvertently hit a transmitter switch, turning it off, thus giving rise to a communications problem which delayed EVA for a while.

There were some lesser problems involving identification of film magazines- which ones were used, and which were still usable; leaking (torn) lunar sample bags; the need for a sight for aiming the lunar surface TV camera; and, finally, the toppling of instruments when relatively rigid cables were attached to them, during first EVA.